ADA

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITY AND PREVENTING PUMP FAILURE AT HIGH TEMPERATURE

INTERIM REPORT
TFLRF No. 437

by
Douglas M. Yost
Adam C. Brandt
Ruben A. Alvarez

U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

for
Patsy Muzzell
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD0004–Task XVI)

January 2013

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14. ABSTRACT

Stanadyne rotary injection pump tests were conducted to determine the effectiveness of using approved MIL-PRF-25107 DCI4-A, NALCO5403 corrosion improver/lubricity improver (CI/LI) and a commercial diesel lubricity improver in selected concentrations in improving fuel lubricity and preventing premature pump failures at temperatures of 104°F (40°C), 135°F (57°C), and 170°F. Certification 2007 Diesel, Jet A, FT-SPK neat and FT-SPK blended with Jet A were used to perform a total of 21 tests. Evaluations determined that diesel fuel and clay treated diesel fuel operated for 1000-hours will reveal detrimental effects on fuel injection pump specification performance. Jet A-1 aviation kerosene fuel and FT-SPK fuel unblended without any CI/LI Additives should not be used in rotary, fuel-lubricated, fuel injection pumps. CI/LI Additives greatly Improve Durability of both Jet A-1 fuel and the alternative aviation fuel FT-SPK at relatively low concentrations. All additives showed substantial improvements in fuel injection pump durability when blended with aviation kerosene fuel. MIL-PRF-25017 additives perform better in aviation kerosene fuels than a Commercial Diesel Fuel additive, and at lower concentrations. MIL-PRF-25017 Additive DCI-4A performed slightly better than the other additives evaluated.

15. SUBJECT TERMS

Rotary injection pump, Nalco 5403, DCI-4A, Certification 2007 Diesel, JET A aviation kerosene, FT-SPK, BOCLE, SLBOCLE, HFRR, lubricity-improver

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EXECUTIVE SUMMARY

Fuel supplies are evolving as more highly processed petroleum fuels, unconventional fuels, and non-petroleum fuels are increasingly making their way into the market place worldwide. As these changes in the supply of fuels occurs around the world, and also in the fuels specified for future engines/equipment designs, the U.S. Military needs to understand the extent and nature of these changes and the implications regarding current and future use.

An evaluation program was initiated to determine the effectiveness of MIL-PRF-25017, and a commercially available diesel fuel additive, in improving fuel lubricity to prevent rotary fuel injection pump failure when operating at elevated fuel inlet temperatures on current and potential future military fuels. A series of twenty-one tests were performed, at durations of up to 1,000-hours.

For virtually all fuels, including diesel fuel, after 1,000-hours of operation a large number of fuel injection pumps exhibited compromised low idle delivery characteristics. Most of the compromised would result in rough idle, fast or slow idle, surging, or outright idle stall. Several of the fuel injection pumps exhibited compromised governor action for engine over-speed protection; some the cut-out speed started at lower engine speed, and one pump over-fueled at the cut-out speed. Several pumps had delivery characteristics near the peak torque and rated power speeds that could reduce peak torque and rated power. One fuel injection pump exhibited cranking delivery reductions that would impact engine starting.

Observations regarding diesel fuel, aviation and alternative aviation kerosene fuels and blends thereof, and the effectiveness of Corrosion Inhibitor/Lubricity Improver (CI/LI) additives follow.

- Some detrimental effects on fuel injection pump specification performance were observed even when testing diesel fuel for 1,000-hours.
- Jet A-1 and FT-SPK fuel unblended and WITHOUT any CI/LI Additives Should NOT be Used in rotary, fuel-lubricated, fuel injection pumps

- CI/LI Additives greatly improve durability of both Jet A-1 fuel and the alternative aviation fuel FT-SPK at relatively low concentrations. All additives showed substantial improvements in fuel injection pump durability when blended with aviation kerosene fuel.
- MIL-PRF-25017 Additives perform better in aviation kerosene fuels than a commercial diesel fuel additive, and at lower concentrations.
- MIL-PRF-25017 Additive DCI-4A performed slightly better than the other additives evaluated.

Based on the bench lubricity test results, and the fuel injection pump component wear assessments the following recommendations were made.

- The MIL-PRF-25017 maximum effective concentration for the CI/LI additive DCI-4A, 22.5 mg/L, appears to offer adequate protection for rotary fuel injection pumps at fuel inlet temperatures up to 170°F (77°C) for both Jet A-1 and alternative aviation kerosene
- The MIL-PRF-25017 minimum effective concentration for the CI/LI additive DCI-4A, 9-mg/L, offers INADEQUATE protection for rotary fuel injection pumps at 170°F (77°C) fuel inlet temperatures with the 50/50 Jet A-1/alternative aviation fuel blend.
- It is recommended for continuous operations in elevated temperature environments, the MAXIMUM treatment rate of MIL-PRF-25017 additives should be utilized in aviation kerosene fuel in order to protect rotary fuel injection pumps.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period April 2009 through January 2013 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Eric Sattler served as the TARDEC contracting officer's technical representative. Ms. Patsy Muzzell of TARDEC served as project technical monitor.

The authors would like to acknowledge the contribution of the TFLRF technical support staff along with the administrative and report-processing support provided by Dianna Barrera.

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ACRONYMS AND ABBREVIATIONS

2DS15	No. 2 Diesel fuel with 15-ppm Sulfur
ASTM	American Society for Testing and Materials
BOCLE	Ball On Cylinder Lubricity Evaluator
CARB	California Air Resources Board
cc	Cubic Centimeter, volume measure
CDA	Commercial Diesel Fuel Additive
CI/LI	Corrosion Inhibitor/Lubricity Improver
DF2	Diesel Fuel, No. 2 Grade
FT	Fischer-Tropsch
FT-SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene
HFRR	High Frequency Reciprocating Rig
HMMWV	High Mobility Multi-Purpose Wheeled Vehicle
kW	Kilowatt
mg/L	milligrams per Liter concentration
MI	Michigan
MIL-PRF-25017	Military Performance Specification number 25017
QPL	Qualified Products List
RDECOM	Research, Development, and Engineering Command
rpm	Revolutions Per Minute
SLBOCLE	Scuffing Load Ball On Cylinder Lubricity Evaluator
SLWT	Scuffing Load Wear Test (SLBOCLE)
SPK	Synthetic Paraffinic Kerosene
TARDEC	Tank-Automotive Research, Development, and Engineering Center
TFLRF	TARDEC Fuels and Lubricants Research Facility
U.S.	United States
ULSD	Ultra Low Sulfur Diesel fuel
WOT	Wide Open Throttle
WPAFB	Wright-Patterson Air Force Base

1.0 BACKGROUND

Fuel supplies are evolving as more highly processed petroleum fuels, unconventional fuels, and non-petroleum fuels are increasingly making their way into the market place worldwide. Some of this evolution begun several years ago when, for instance environmental legislation in the U.S. mandated cleaner tailpipe emissions and as a result, the need for more highly processed fuels, i.e., lower sulfur and lower aromatic content fuels as California Air Resources Board (CARB) Diesel and Ultra Low Sulfur Diesel (ULSD) fuels. The move toward developing and using non-petroleum fuels, such as biodiesel, renewable diesel/jet fuel or Fisher-Tropsch fuels is occurring in many countries as spurred by high volatility in the oil market, especially since 2006. In addition, much of the impetus behind transitioning to alternative fuels is tied to the desire of nations to better secure their energy supply by reducing dependence on foreign sources of oil through conversion of in-country energy resources such as tar sands, shale oil, coal, natural gas, biomass/waste streams (renewable) into transportation fuels. As these changes in the supply of fuels occurs around the world, and also in the fuels specified for future engines/equipment designs, the U.S. Military needs to understand the extent and nature of these changes and the implications regarding current and future use.

2.0 INTRODUCTION

The U.S. Army RDECOM-TARDEC, Force Projection Technology Team at Warren, MI, sponsored this project to determine the effectiveness of MIL-PRF-25017 and a commercially available diesel fuel additive in improving fuel lubricity to prevent fuel injection pump failure when operating at elevated fuel temperatures. The TARDEC Fuels and Lubricants Research Facility (TFLRF) at Southwest Research Institute® conducted the evaluations.

Rotary fuel injection pump test rigs were used to conduct the testing and were configured to test pumps representative of current HMMWV production engines. Duplicate pump rig tests were conducted for each unique test fuel and fuel additive combination and each pump rig test was conducted for a duration of 1,000 hours maximum or until pump failure.

Standard fuel property testing was conducted on each test fuel in addition to selected analyses requested by sponsor. Bench-top lubricity testing consisting of ASTM D6078 (HFRR), ASTM D6078 (SLBOCLE) also known as Scuffing Load Wear Test (SLWT), and ASTM D5001 (BOCLE) were performed on each test fuel (fuel additive combination). Table 1 shows the test matrix that was used to perform the required evaluations.

Table 1. Stanadyne Rotary Pump Lubricity Tests Matrix

Test No.	Test Fuel	Properties Data	Bench-Top Lubricity Data	105°F (40.6°C)	135°F (57.2°C)	170°F (76.7°C)
1, 2, 3	No. 2DS15 Certified 2007 as Purchased	ASTM D975	X	X	X	X
4	No. 2DS15 Certified 2007 Clay Treated		X	X		
5	JetA-1, No CI/LI	ASTM D1655	X	X		
6,8,10	JetA-1 with DCI-4A @ 22.5g/m³		X	X	X	X
7,9,11	JetA-1 with Nalco 5403 @ 22.5g/m³		X	X	X	X
12,13,14	JetA-1 with commercial additive @ max rate		X	X	X	X
15	SPK No CI/LI (Alternative Aviation Fuel)	ASTM D1655	X	X		
16,17,18	Fuel used in test 15 with best QPL additive from tests above (max treat)			X	X	X
19,20,21	50/50 % Blend of SPK and JetA-1 Fuel with best QPL Additive at 9ppm treat rate	ASTM D1655	X	X	X	X

3.0 PROGRAM OBJECTIVES

The program objectives were:

- To perform test rig bench tests on Stanadyne model DB2831-5079 rotary injection pumps with selected diesel, Jet A-1, SPK, and SPK/Jet A-1 blend fuels, neat and additized with approved MIL-PRF-25017 DCI4-A, MIL-PRF-25017 Nalco 5403 Corrosion Improver and Lubricity Improver (CI/LI) additives, and a commercial diesel fuel lubricity improver in accordance with Table 1.
- To determine the effectiveness of additives in improving fuel lubricity and preventing premature pump failures at fuel inlet temperatures of 105°F (40°C), 135°F (57°C), and 170°F (77°C).
- To evaluate test results and determine effects of the lubricity improver additives or lack thereof on rotary pump performance at the three selected temperatures.

4.0 DETAILS OF EVALUATION

4.1 TEST FUELS

The array of fuels selected for these evaluations were:

- Ultra Low Sulfur Diesel Fuel, ULSD; neat and clay treated
- Jet A-1 Fuel; with and without CI/LI additive
- Fischer-Tropsch SPK Fuel; with and without CI/LI additive
- 50/50 Jet A-1/alternative blend; with CI/LI additive

BOCLE (Ball-On-Cylinder Lubricity Evaluation), SLWT (Scuffing Load Wear Test) also known as SLBOCLE, and HFRR (High Frequency Reciprocating Rig) analyses were performed at specific intervals throughout the testing sequences. The BOCLE tester is shown in Figure 1, the SLWT instrument is shown in Figure 2, and the HFFR tester is shown in Figure 3.

Table 2 shows the description, source of the neat fuels and location of the fuel provider. Table 3 shows the fuel properties of the various aviation kerosene fuels utilized for testing. The aviation kerosene fuel was purchased as Jet A, but the fuel also meets the Jet A-1 freeze point specification, so for this program it is considered Jet A-1. The fuel properties for the ULSD used for testing are shown in Table 4.

Table 2. Description of Non-Additized Test Fuels

Fuel Description	Fuel Source	Location
No. 2DS15 Certified 2007 Diesel	Haltermann Solutions	Channelview, Texas
Aviation Fuel Jet A-1	Valero Refinery	Three Rivers, Texas
Synthetic Paraffinic Kerosene	Shell	WPAFB

Table 3. Test Fuel Properties, Jet A-1, SPK, SPK/Jet A-1 Blend

ASTM Method	Property	Specification	Jet A-1	SPK	SPK/Jet A-1 (50/50%)
D3242	Acidity, total mg KOH/g	0.1 max	0.001		0.004
D1319	Aromatics, vol %	25 max	20.5	0.90	8.30
D3227	Sulfur, mercaptan wt %	0.003 max	<0003	<0003	<0003
D2622	Sulfur, total weight %	0.3 max	<0.001	<0.001	<0.001
D86	Distillation temp °C				
	Initial boiling point, temp		160.4	153.3	162
	2% recovered, temp				166.6
	5% recovered, temp		173	162.2	168.7
	10% recovered, temp	205 max	173.7	163.2	168.9
	20% recovered, temp		175.9	164.3	171
	50% recovered, temp	Report	184.8	170.8	179.2
	90% recovered, temp	Report	206.2	189.9	202.4
	FBP, temp		219.1	216.3	223.9
	Recovery, vol %		97.8	98.5	98.6
	Distillation Residue, %	1.5 max	1.2	1.2	1.2
	Distillation Loss, %	1.5 max	1	0.3	.1
D56	Flash point, °C	38 min	48	42	37
D4052	Density at -15°C, kg/m³		0.801	0.742	0.769
D2386	Freezing Point, °C	-40 max	-60	-55	-68
D445	Viscosity at -20˚C mm²/s	6 max	3.18	2.58	3.00
	Viscosity at 40˚C mm²/s		1.09	0.95	1.03
	Viscosity at 57˚C mm²/s		0.89	0.78	0.85
	Viscosity at 77˚C mm²/s		0.73	0.65	0.69
	Viscosity at 100˚C mm²/s		0.59	0.53	0.57
D4529	Net heat of combustion, MJ/kg	42.8 min	43.2	42	43.48
	Gross heat of combustion, MJ/kg		45.5	44.3	ND
D1322	Smoke point, mm	25 min	21.8		35
D130	Corrosion strip 2hr@100°C	No. 1 max	1B	1A	1A

ASTM Method	Property	Specification	Jet A-1	SPK	SPK/Jet A-1 (50/50%)
D3241	Filter pressure drop, mm Hg	25 max	1	1	1
D381	Existent gum, mg/100mL	7 max	1.5	1	1
D3948	Microseporometer, rating				
	W/O electrical conductivity additive	86 min	99	99	98
D2624	Electrical conductivity , pS/m	600 max	0	11	7

Table 4. Test Fuel Properties, No. 2DS15 Certified 2007 Diesel

ASTM Method	Property	Specification	No. 2DS15 Cert 2007 Diesel
D93	Flash Point, °C	52 min	76.6
D2709	Water and Sediment, vol %	0.05 max	0.01
D86	Distillation temp °C		
	Initial boiling point, temp	171 min; 238 max	193.1
	2% recovered, temp	Report	
	5% recovered, temp	Report	210.7
	10% recovered, temp	204min; 238max	216.9
	20% recovered, temp	Report	228.6
	50% recovered, temp	243min; 282max	255.8
	90% recovered, temp	293min; 332max	308.5
	FBP, temp	321min; 365max	341
	Recovery, vol %	Report	98.2
	Distillation Residue, vol %	Report	2.2
	Distillation Loss, vol %	Report	0.08
D445	Viscosity at -20˚C mm²/s	1.9 min/4.1 max	
	Viscosity at 40˚C mm²/s		2.53
	Viscosity at 57˚C mm²/s		0.77
	Viscosity at 77˚C mm²/s		0.59
	Viscosity at 100˚C mm²/s		
D482	Ash, mass %	0.01	<0.001
D2622	Sulfur, mass%	0.0005	0.0014
D130	Copper strip corrosion	No.3	No.3
D613	Cetane number	40 min	44
D1319	Aromatics, vol %	35 max	29.5
D2500	Cloud point, °C	max	-25
D524	Ramsbottom carbon residue on 10% distillation residue, mass %	0.35 max	0.07
D6079	Lubricity, HFRR@60°C micron	520 max	310
D2624	Conductivity, pS/m	25 min	

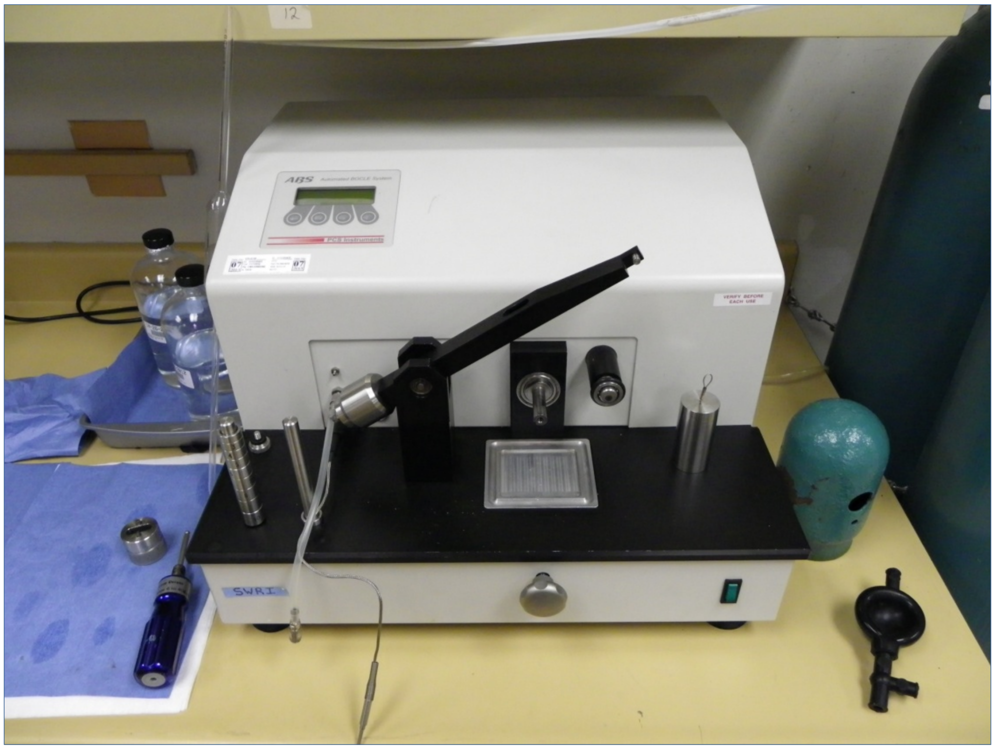


Figure 1. Ball-on-Cylinder Lubricity Evaluator (BOCLE) Tester

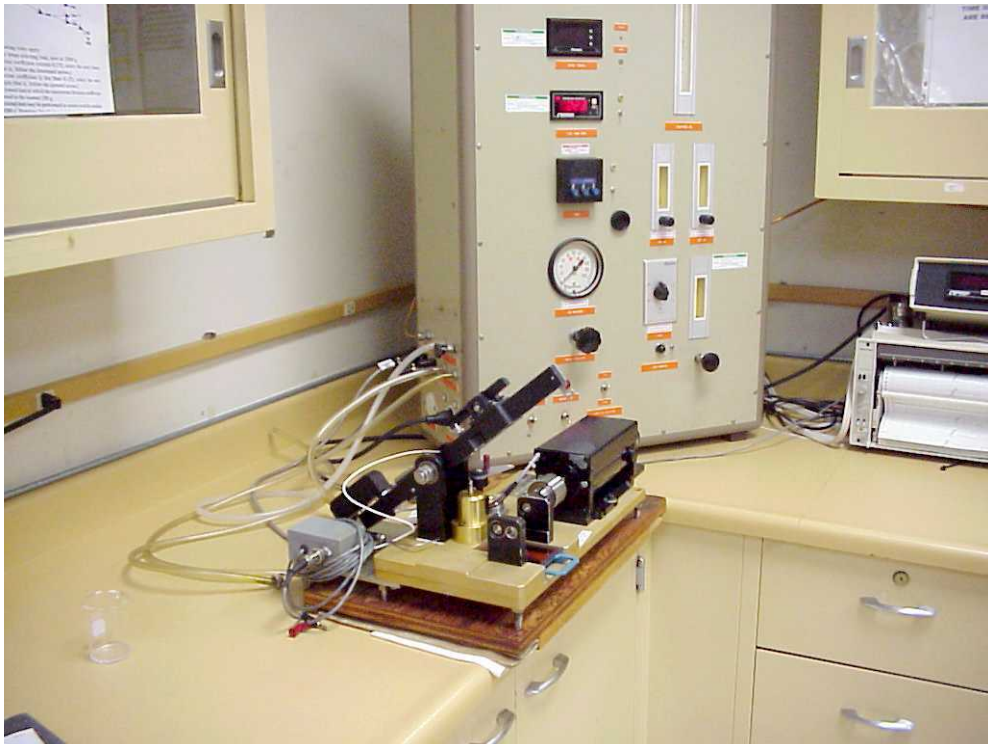


Figure 2. Scuffing Load Wear Test (SLBOCLE) Instrument

Figure 3. High Frequency Reciprocating Rig (HFRR)

4.2 ROTARY PUMP TEST PROCEDURES

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated and mechanically governed injection pumps, model DB2831-5079, for a General Engine Products 6.5L Turbocharged engine application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. The rotary distributor injection pump is wear rate sensitive to the combination of low viscosity and low lubricity properties of military mobility fuels. A schematic diagram of the principal pump components is provided in Figure 4.

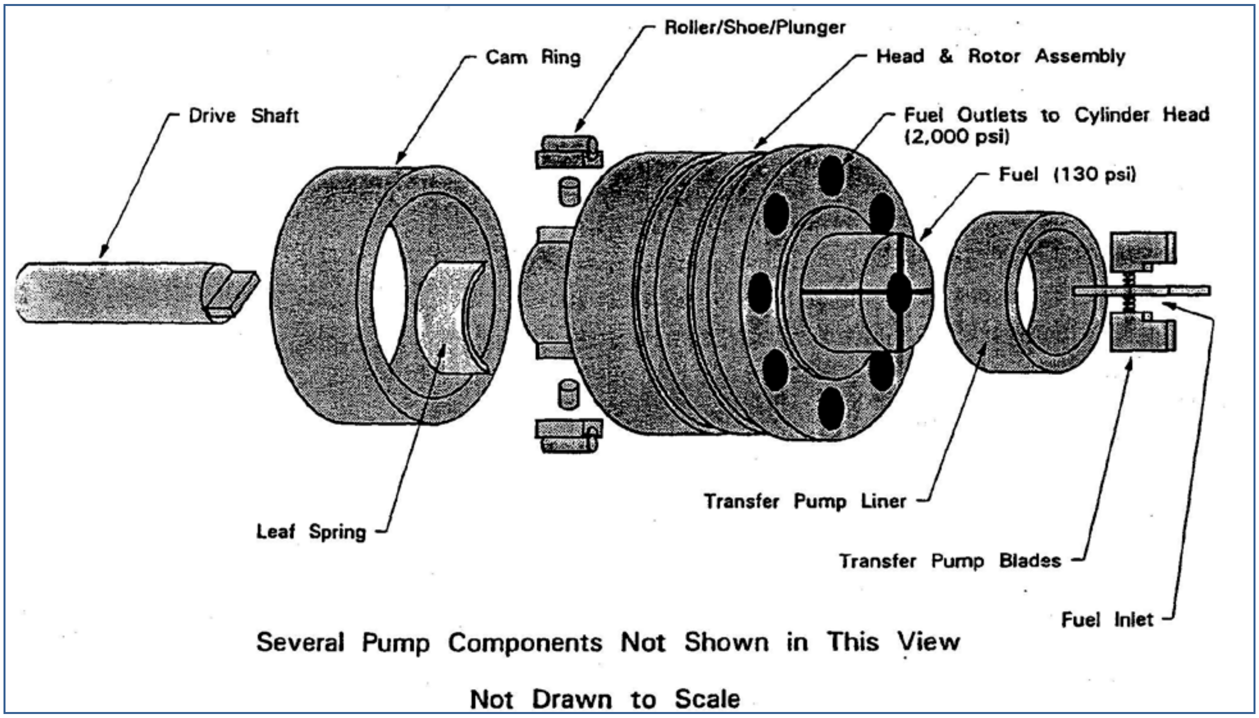


Figure 4. Schematic Diagram of Principal Pump Components

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model, edition 4, dated 05-02-95. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are not any min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

The pumps were reassembled and pre-test performance evaluations were conducted. The pumps were then mounted on the test stand and operated at 1,700 rpm, with the fuel levers in the wide open throttle position (WOT) for targeted 1,000-hour increments (or less). Fuel injected flow rate, fuel inlet and fuel outlet and fuel tank temperatures, fuel inlet and transfer pump and pump housing pressures, and RPM were tracked and recorded. Any wear in the fuel injection pump metering section was reflected as an increased or reduced flow reading. The fuel inlet temperature was controlled at temperatures +/-5 degrees from testing temperatures. Inlet temperature variations directly affect the fuel return temperature, which is a function of accelerated pump wear. The transfer pump pressure is the regulated pressure the metal blade transfer pump supplies to the pump metering section. With low lubricity fuels, wear is likely to occur in the transfer pump blades, blade slots, and eccentric liner. Wear in these areas generally causes the transfer pump pressure to decrease. However, because the transfer pump has a pressure regulator, significant wear needs to occur in the transfer pump before the fuel pressure drops to below the operating range allowed in the pump specification. The housing pressure is the regulated pressure in the pump body that affects fuel metering and timing. With low lubricity fuel, wear occurs in high fuel pressure generating opposed plungers and bores, and between the hydraulic head and rotor. Leakage from the increased diametrical clearances of the plunger bores and the hydraulic head and rotor, results in increased housing pressures. Increased housing pressure reduces metered fuel and retards injection timing.

4.3 CYCLE DESCRIPTION

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

4.4 PUMP TEST STAND

The rotary pumps were tested on test stands with a common fuel supply. To ensure a realistic test environment, the mounting arrangement and drive gear duplicate that of the GEP 6.5L engine. The fuel was maintained in a 55-gallon drum and continuously recirculated throughout the duration of each test. A centrifugal pump provided a positive head of 3 psi at the inlet to the test pumps. A cartridge filter corresponding to that used in the GEP 6.5L engine in the HMMWV was used to remove wear debris and particulate contamination. Finally, a 5-kW Chromalox explosion-resistant circulation heater produced the required fuel inlet temperature.

The high-pressure outlets from the pumps were connected to eight Bosch model fuel injectors for a GEP 6.5L turbocharged engine and assembled in a collection canister. Fuel from both canisters was then returned to the 55-gallon drum. A separate line was used to return excess fuel from the governor housing to the fuel supply. Fuel-to-water heat exchangers on both the return lines from the injector canisters and the governor housing were used to cool the fuel. The fuel system schematic used for the tests is depicted in Figure 5. The motorized test stands are shown in Figure 6 and Figure 7.

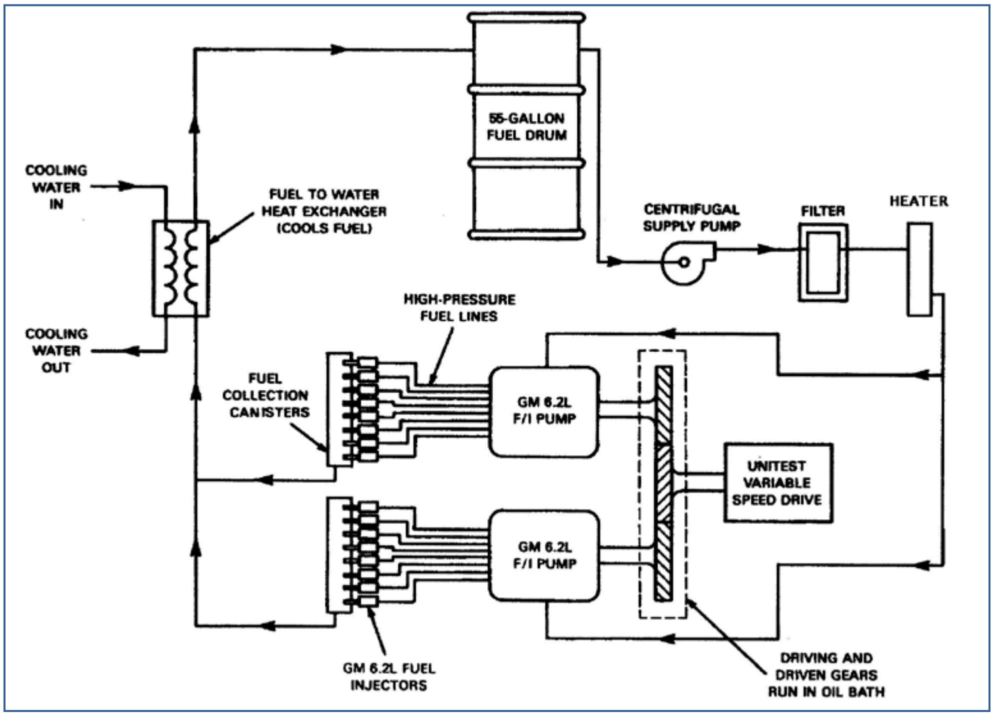


Figure 5. Representative Fuel System Schematic

Figure 6. Cell 4 Pump Stand

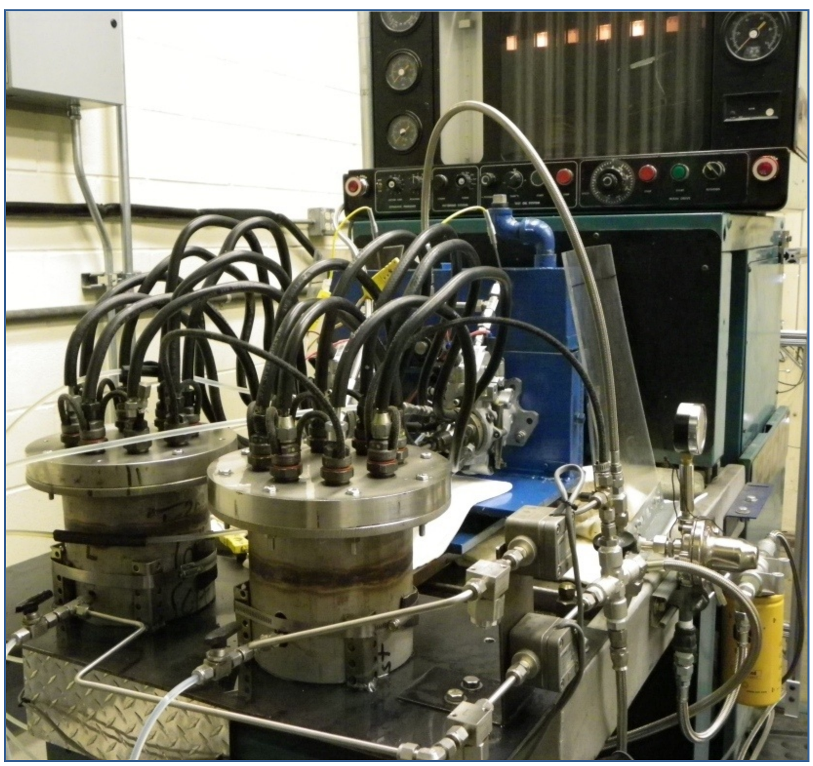


Figure 7. Cell 3 Pump Stand

5.0 DISCUSSION AND RESULTS

A majority of the pumps completed 1,000 hours of operation without catastrophic failure; however, there is wear that could occur within the pumps that would cause the pump to be out of specification. During the calibration checks there are combinations of 22-parameters evaluated at different pump speeds that may include delivery, fuel pressure, or timing. The number of instances where a pump was outside the specification range is summarized in Table 5. Included in Table 5 are an assessment of fuel related impacts on the fuel injection pump. It should be noted that with the exception of the pumps that experienced head and rotor seizure or failed catastrophically for other reasons that prevented post-calibration, the pumps remained operational.

Selected components known to wear with low lubricity fuels were evaluated subjectively for wear, with 0=new, and 5=failed. The pump rating is an average of the subjective ratings for all components evaluated. All fuel injectors used in testing were evaluated prior to testing and again at the conclusion of the test. The number of injectors that fell outside the injector performance specification at the conclusion of testing is also noted. Injectors used for these pump tests were subjected to wide open throttle operation for the duration of the test. Post-test fuel injector condition and performance test results may not be indicative of typical in-vehicle field operation. An injector with decreased opening pressure will probably “fail” the chatter test and more than likely “fail” the spray pattern test. In a typical vehicle application, this condition could cause erratic engine operation, increased smoke emission, or decreased power, which may actually go unnoticed depending on the severity of the condition. Likewise, a leakage test failure would cause increased smoke emission upon engine start, which may also go unnoticed.

Specifics on the test cycle operating parameters, pump operation summaries, graphical plots for key operating conditions for average flow rate, transfer pump & housing pressure, and fuel inlet & return temperatures, are found in Appendix A through Appendix U for each of the 21 tests performed. Before and after pump calibrations, transfer pump blade measurements, injector nozzle tests, pump parts evaluation, and parts conditions photographs are also found in the Appendices.

Table 5. Summarized Testing Results for Fuel Additive Effectiveness at Elevated Temperature

Test No.	Pump SN	Fuel Type	Fuel Temp. F° (C°)	Target Hrs.	Test Hrs	Test Summary	Bench Top Lubricity		
						Pump Rating 0= (Best) 5= (Fail)	BOCLE mm	SLBOCLE grams	HFRR mm
1	1-15293084	DF2 As Purchased	105 (40)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.04 Failed Injectors–0	0.53	5,500	0.257
1	2-15293089	DF2 As Purchased	105 (40)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.04 Failed Injectors–0	0.53	5,500	0.257
2	1-15382732	DF2 As Purchased	135 (57)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.13 Failed Injectors–0	0.55	5,400	0.310
2	2-15382733	DF2 As Purchased	135 (57)	1,000	1,000	Calibration off spec areas–3 Pump Rating–1.15 Failed Injectors–0	0.55	5,400	0.310
3	1-15396933	DF2 As Purchased	170 (77)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.13 Failed Injectors–0	0.49	6,000	0.294
3	2-15396934	DF2 As Purchased	170 (77)	1,000	1,000	Calibration off spec areas–5 Pump Rating–1.07 Failed Injectors–2	0.49	6,000	0.294
4	1-15396475	DF2 Clay Treated	105 (40)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.54 Failed Injectors-0	0.55	4,400	0.640
4	2-15396930	DF2 Clay Treated	105 (40)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.60 Failed Injectors1	0.55	4,400	0.640
5	1-15396931	Jet A-1 No Additive	105 (40)	1,000	124.5	Calibration off spec areas–6 Pump Rating–1.9 (Pump removed) Failed Injectors–0 Note: Pump was indicating accelerated wear early into the test. When companion pump failed, component was removed to avoid seizure to be able to calibrate flows and determine degree of wear.	0.78	1800	0.603
5	2-15396932	Jet A-1 No Additive	105 (40)	1,000	124.5	Calibration off spec areas–(no EOT Cal) Pump Rating–5 (Head seized) Failed Injectors–0 Note: From the beginning of the test, the average fuel flow reading began to increase indicating accelerated wear. The right pump seized at 124.5 hrs into the test.	0.78	1800	0.603

Test No.	Pump SN	Fuel Type	Fuel Temp. F° (C°)	Target Hrs.	Test Hrs	Test Summary	Bench Top Lubricity		
						Pump Rating 0= (Best) 5= (Fail)	BOCLE mm	SLBOCLE grams	HFRR mm
6	1-15396935	Jet A-1 w/DCI-4A (Max Rate)	105 (40)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.4 Failed Injectors–0	0.64	2500	0.653
6	2-15396948	Jet A-1 w/DCI-4A (Max Rate)	105 (40)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.6 Failed Injectors–0	0.64	2500	0.653
7	1-15396949	Jet A-1 w/Nalco 5403 (Max Rate)	105 (40)	1,000	1,000	Calibration off spec areas–3 Pump Rating–1.6 Failed Injectors–2	0.53	2200	0.664
7	2-15396950	Jet A-1 w/Nalco 5403 (Max Rate)	105 (40)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.4 Failed Injectors–0	0.53	2200	0.664
8	1-15396951	Jet A-1 w/DCI-4A (Max Rate)	135 (57)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.5 Failed Injectors–0	0.60	1950	0.680
8	2-15396952	Jet A-1 w/DCI-4A (Max Rate)	135 (57)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.4 Failed Injectors–0	0.60	1950	0.680
9	1-15396953	Jet A-1 w/Nalco 5403 (Max Rate)	135 (57)	1,000	1,000	Calibration off spec areas–(No EOT cal) Pump Rating–1.4 Failed Injectors–0	0.58	2650	0.701
9	2-15396954	Jet A-1 w/Nalco 5403 (Max Rate)	135 (57)	1,000	1,000	Calibration off spec areas–3 Pump Rating–1.5 Failed Injectors–0	0.58	2650	0.701
10	1-15396955	Jet A-1 w/DCI-4A (Max Rate)	170 (77)	1,000	1,000	Calibration off spec areas–3 Pump Rating–1.3 Failed Injectors–0	0.60	2650	0.720
10	2-15396956	Jet A-1 w/DCI-4A (Max Rate)	170 (77)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.3 Failed Injectors–0	0.60	2650	0.720
11	1-15438592	Jet A-1 w/Nalco 5403 (Max Rate)	170 (77)	1,000	1,000	Calibration off spec areas–7 Pump Rating–1.6 Failed Injectors–0	0.59	2600	0.710
11	2-15438593	Jet A-1 w/Nalco 5403 (Max Rate)	170 (77)	1,000	1,000	Calibration off spec areas–6 Pump Rating–1.8 Failed Injectors–0	0.59	2600	0.710
12	1-15438594	Jet A-1 w/OLI-9070x (Min rate)	105 (40)	1,000	1,000	Calibration off spec areas–1 Pump Rating–1.5 Failed Injectors–2	0.64	2450	0.710
12	2-15438595	Jet A-1 w/OLI-9070x (Min rate)	105 (40)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.6 Failed Injectors–0	0.64	2450	0.710
13	1-15438596	Jet A-1 w/OLI-9070x (Min rate)	135 (57)	1,000	1,000	Calibration off spec areas–5 Pump Rating–1.5 Failed Injectors–0	0.63	1850	0.720

Test No.	Pump SN	Fuel Type	Fuel Temp. F° (C°)	Target Hrs.	Test Hrs	Test Summary	Bench Top Lubricity		
						Pump Rating 0= (Best) 5= (Fail)	BOCLE mm	SLBOCLE grams	HFRR mm
13	2-15438597	Jet A-1 w/OLI-9070x (Min rate)	135 (57)	1,000	1,000	Calibration off spec areas–4 Pump Rating–1.6 Failed Injectors–0	0.63	1850	0.720
14	1-15438598	Jet A-1 w/OLI-9070x (Min rate)	170 (77)	1,000	750	Calibration off spec areas–(No EOT cal) Pump Rating–2.1 Failed Injectors–0 Note: Test stand was shut down at 750 hours for fuel drum change. Immediately after restart, fuel began spewing out of test stand gear box and the test was stopped. Investigation revealed that housing needle bearings had worn excessively creating friction and heat that disintegrated two driveshaft seals which allowed fuel to flow into the gearbox. Pump was removed and test continued with the right pump.	0.65	1600	0.730
14	2-15438599	Jet A-1 w/OLI-9070x (Min rate)	170 (77)	1,000	1,000	Calibration off spec areas–5 Pump Rating–1.8 Failed Injectors–0	0.65	1600	0.730
15	1-15438603	FT-SPK no CI/LI	105 (40)	1,000	.59	Calibration off spec areas–(No EOT cal) Pump Rating–1.8 Failed Injectors–0 Note: Left pump seized 35 minutes into the test. No anomalies were noted prior to the seizure.	1.01	1200	0.840
15	2-15438885	FT-SPK no CI/LI	105 (40)	1,000	48	Calibration off spec areas–(No EOT cal) Pump Rating–1.9 Failed Injectors–0 Note: Right pump seized 48 hrs into the test. Average fuel flow increased approximately 14 percent; therefore the stand was shut down and the governor top cover was removed to check for wear debris. No wear debris was found, top cover replaced and the test stand restarted. The pump seized as the test stand (700 rpm) was ramping up.	1.01	1200	0.840
16	1-15438886	FT-SPK w/DCI-4A (max Rate)	105 (40)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.8 Failed Injectors–2	0.65	1850	0.800
16	2-15438887	FT-SPK w/DCI-4A (max Rate)	105 (40)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.8 Failed Injectors–4	0.65	1850	0.800
17	1-15438888	FT-SPK w/DCI-4A (max Rate)	135 (57)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.9 Failed Injectors–2	0.65	1850	0.800

Test No.	Pump SN	Fuel Type	Fuel Temp. F° (C°)	Target Hrs.	Test Hrs	Test Summary	Bench Top Lubricity		
						Pump Rating 0= (Best) 5= (Fail)	**BOCLE mm**	**SLBOCLE grams**	**HFRR mm**
17	2-15438889	FT-SPK w/DCI-4A (max Rate)	135 (57)	1,000	1,000	Calibration off spec areas–1 Pump Rating–2 Failed Injectors–0	0.65	1850	0.800
18	1-15438891	FT-SPK w/DCI-4A (max Rate)	170 (77)	1,000	1,000	Calibration off spec areas–1 Pump Rating–1.6 Failed Injectors–1	0.56	1800	0.784
18	2-15438892	FT-SPK w/DCI-4A (max Rate)	170 (77)	1,000	1,000	Calibration off spec areas–3 Pump Rating1.6– Failed Injectors–1	0.56	1800	0.784
19	1-15442444	FT-SPK/Jet A-1 w/ DCI-4A (min rate)	105 (40)	1,000	1,000	Calibration off spec areas–1 Pump Rating-1.7– Failed Injectors–0	0.73	2100	0.681
19	2-15442445	FT-SPK/Jet A-1 w/ DCI-4A (min rate)	105 (40)	1,000	1,000	Calibration off spec areas–2 Pump Rating–1.8 Failed Injectors–0	0.73	2100	0.681
20	1-15442663	FT-SPK/Jet A-1 w/ DCI-4A (min rate)	135 (57)	1,000	1,000	Calibration off spec areas–5 Pump Rating–2.1 Failed Injectors–0	0.78	1450	0.727
20	2-15442664	FT-SPK/Jet A-1 w/ DCI-4A (min rate)	135 (57)	1,000	1,000	Calibration off spec areas–2 Pump Rating–2.2 Failed Injectors–0	0.78	1450	0.727
21	1-15848225	FT-SPK/Jet A-1 w/ DCI-4A (min rate)	170 (77)	1,000	418	Calibration off spec areas–4 Pump Rating–2.1 Failed Injectors–0 Note: The test stand was stopped at 418 hours into the test when the remaining left pump became very noisy and the fuel moving average had dropped approximately 16% from start of test.	0.75	1700	0.719
21	1-15848373	FT-SPK/Jet A-1 w/ DCI-4A (min rate)	170 (77)	1,000	372	Calibration off spec areas–8 Pump Rating–2.6 Failed Injectors–0 Note: By 372 hours into the test the right pump displayed a notable drop (approx) 25% in the fuel moving average. The test stand was shut down and the top cover removed from the pump to inspect for excessive wear. Heavy metal shavings were seen in the solenoid assembly and the pump was removed from the stand to prevent rotor seizure.	0.75	1700	0.719

5.1 TESTS 1, 2, AND 3 - NO. 2DS15 CERTIFIED 2007 DIESEL (AS PURCHASED)

Tests 1, 2 and 3 were conducted using the certified diesel fuel at temperatures of 105°F (40°C), 135°F (57°), and 170°F (77°C) for a targeted 1,000 pump stand hours. The assumption was made that the pumps would operate normally for the prescribed 1,000-hours; therefore, the subsequent tests would be compared to the results obtained using the certified diesel fuel. The three sets of pumps completed the 1,000-hours of testing with no anomalies noted during operation.

5.1.1 Test 1 Fuel Injection System Performance Observations

Test 1 with diesel fuel at 105°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15293084 there were 5 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed that would be one-half the engine speed. Fuelling quantities are noted as cc/1,000-strokes. Two deviations were small timing variations that would not impact operability of an engine. The low idle injection quantity at 350 rpm was measured at 9-cc, where the specification has a 12-cc minimum. This would suggest poor idle stability or low idle speed with pump SN15293084. The fuel delivery at 900 rpm was 3.5-cc below specification (66.5-cc minimum), and the delivery was 1-cc low at 200 rpm (58-cc minimum). The delivery loss at 900 rpm may impact engine peak torque.

For fuel injection pump SN15293084 there was an average 8.4-mg increase in transfer blade weight over the four blades, a 0.004-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.043 (0=new, 5=fail). The transfer pump blades are sintered metal, and likely absorbed fuel to gain weight, or gain weight due to fuel deposition. In addition all fuel injectors passed the post test performance checks.

For pump SN15293089 there were 3 occurrences of post-test calibration parameters falling out of specification. Most were minor variations that would not impact operability of an engine. The low idle injection quantity was measured at 9-cc/1,000-stroke, where the specification has a 12-cc/1,000-stroke minimum. This would suggest poor idle stability, or low idle speed with pump SN15293089. The fuel delivery at 1,825 rpm was measured at 6-cc, whereas the specification calls for 33-cc minimum. The lower delivery at 1,825 rpm means the governor action to reduce engine over-speed is occurring at a lower rpm, typically cut-in is at 1,950 rpm.

For fuel injection pump SN15293089 there was also an average 7.6-mg increase in transfer blade weight over the four blades, a 0.001-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.174 (0=new, 5=fail). The governor performance change shows in the slightly higher subjective wear rating for the companion pump. In addition all fuel injectors passed the post test performance checks.

5.1.2 Test 2 Fuel Injection System Performance Observations

Test 2 with diesel fuel at 135°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15382732 there were 4 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed that would be one-half the engine speed. Fuelling quantities are noted as cc/1,000-strokes. The low idle injection quantity at 350 rpm was measured at 0-cc, where the specification has a 12-cc minimum. In addition the 350 rpm housing pressure had fallen to 3-psi (8-psi minimum). For pump SN15382732 an engine would stall coming down to idle. It is likely this engine would start, but then stall as idle speed is attained, unless the operator increased rack position. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum).

For fuel injection pump SN15382732 there was an average 1.0-mg increase in transfer blade weight over the four blades, a 0.0005-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.130 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15382733 there were 3 occurrences of post-test calibration parameters falling out of specification. Two were variations in reductions of injection timing advance, 1.25° at 350 rpm and the 0.6° at 1,600 rpm that would not greatly impact engine operability. The timing retard at 350 rpm could affect idle stability. The slight retard at 1,600 rpm may not affect peak power, but could affect engine efficiency. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum).

For fuel injection pump SN15382733 there was an average 0.4-mg increase in transfer blade weight over the four blades, a 0.0003-inch increase in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.152 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

5.1.3 Test 3 Fuel Injection System Performance Observations

Test 3 with diesel fuel at 170°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15396933 there were 2 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed and fuelling quantities are cc/1,000-strokes. The low idle injection quantity at 350 rpm was measured at 7-cc, where the specification has a 12-cc minimum. In addition the 350 rpm housing pressure had fallen to 3 psi (8-psi minimum). For pump SN15396933 an engine would likely have a rough idle. There was a 0.5° increase in the fuel injection advance at the 1,600 rpm rated condition that likely would not be noticeable to an operator.

For fuel injection pump SN15396933 there was an average 6.2-mg increase in transfer blade weight over the four blades, a 0.002-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.130 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15396934 there were 5 occurrences of post-test calibration parameters falling out of specification. Two deviations were minor variations that would not impact operability of an engine. The low idle injection quantity at 350 rpm was measured at 2-cc, where the specification has a 12-cc minimum. This would suggest poor idle stability, or idle stalling with pump SN15396934. The fuel delivery at 900 rpm was 2.5-cc below specification (66.5-cc minimum), and the delivery was 1-cc low at 200 rpm (58-cc minimum).

For fuel injection pump SN15396934 there was an average 1.8-mg increase in transfer blade weight over the four blades, a 0.003-inch decrease in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.065 (0=new, 5=fail). Two of the eight fuel injectors failed the post test leakage and spray pattern performance checks.

5.2 TEST 4 - NO. 2DS15 CERTIFIED 2007 DIESEL (CLAY TREATED)

Test 4 was conducted using clay treated certified diesel fuel at temperature of 105°F (40°C) for a targeted 1,000 pump stand hours. The fuel was circulated through Velcon clay filters until the High Frequency Reciprocating Rig (HFRR) reading approximated values found in aviation fuels.

5.2.1 Test 4 Fuel Injection System Performance Observations

Test 4 with clay-treated diesel fuel at 105°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15396475 there were 2 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed that would be one-half the engine speed. Fuelling quantities are noted as cc/1,000-strokes. The two deviations were small timing variations that would not impact operability of an engine. At 350 rpm idle the timing was retarded 1.13° from the specification minimum. At 1,600 rpm full- power the timing was retarded 0.3° from the specification minimum.

For fuel injection pump SN15396475 there was an average 3.2-mg decrease in transfer blade weight over the four blades, a 0.002-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.543 (0=new, 5=fail). The transfer pump blades loss weight due to wear, offsetting gained weight from absorbed fuel. Seven of the eight fuel injectors passed the post test performance checks. The failed injector had a cracked fuel inlet, such that it would not hold pressure and readings were inaccurate. It is likely the fuel inlet cracked due to an improperly installed fuel line, not due to fuel lubricity.

For pump SN15396930 there were 4 occurrences of post-test calibration parameters falling out of specification. Three were minor variations that likely would not impact operability of an engine. The low idle injection quantity was measured at 2-cc/1,000-stroke, where the specification has a 12-cc/1,000-stroke minimum. This would suggest poor idle stability or engine idle stall with pump SN15396930.

For fuel injection pump SN15396930 there was also an average 0.1-mg decrease in transfer blade weight over the four blades, a 0.0015-inch increase in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.565 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

5.3 TEST 5 - JET A-1 NO ADDITIVE

Test 5 was conducted using neat Jet A-1 fuel without any lubricity improver at fuel temperature of 105°F (40°C) for a targeted 1,000 pump stand hours. Both pumps exhibited an early sharp increase in the average fuel flow rate indicating accelerated wear. Pump number 2 on the right seized at 124.5 hours into the test. A decision was reached to stop the test and remove the companion pump number 1 to avoid an imminent seizure thereby allowing the pump to be calibrated.

Figure 8 presents the pump 2 governor assembly with the top covers removed to show the wear debris covering the governor linkages. The seizure location on the rotor of pump 2 can be seen in Figure 9. Figure 10 presents the pump 1 governor linkage with wear debris evident. Early failures with untreated Jet A-1 fuel in Stanadyne rotary fuel injection pumps has been repeatable.

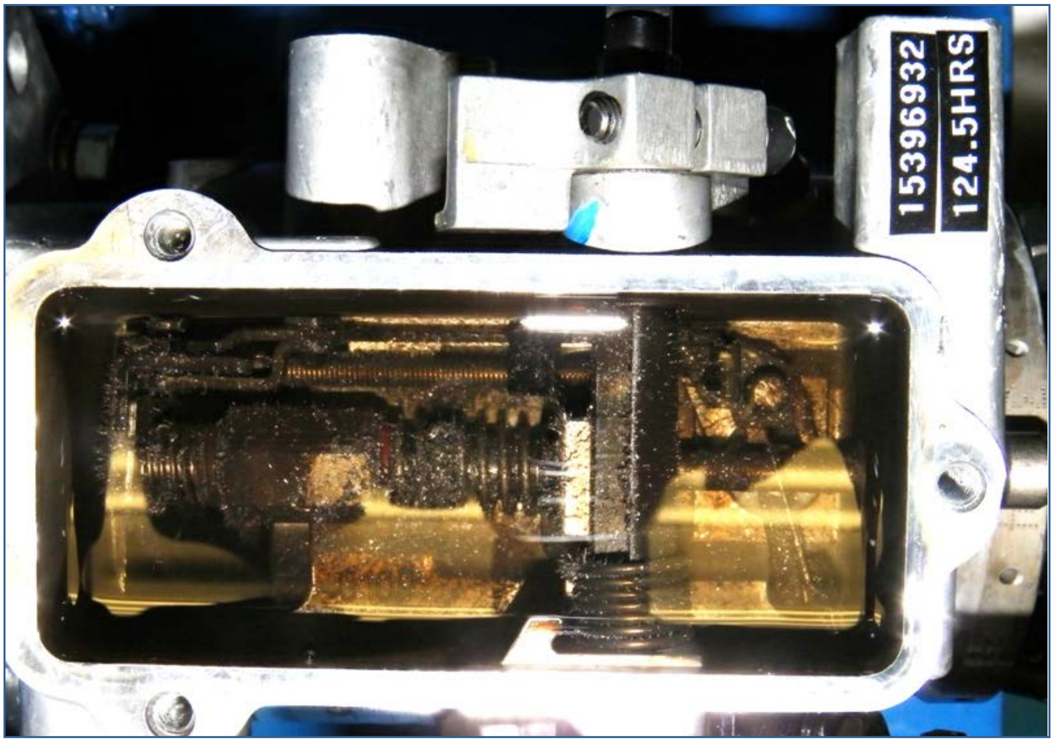


Figure 8. Test 5, Pump 2 (Seized) Governor Linkage Debris

Figure 9. Test 5, Pump 2 Rotor Showing Location of Seizure

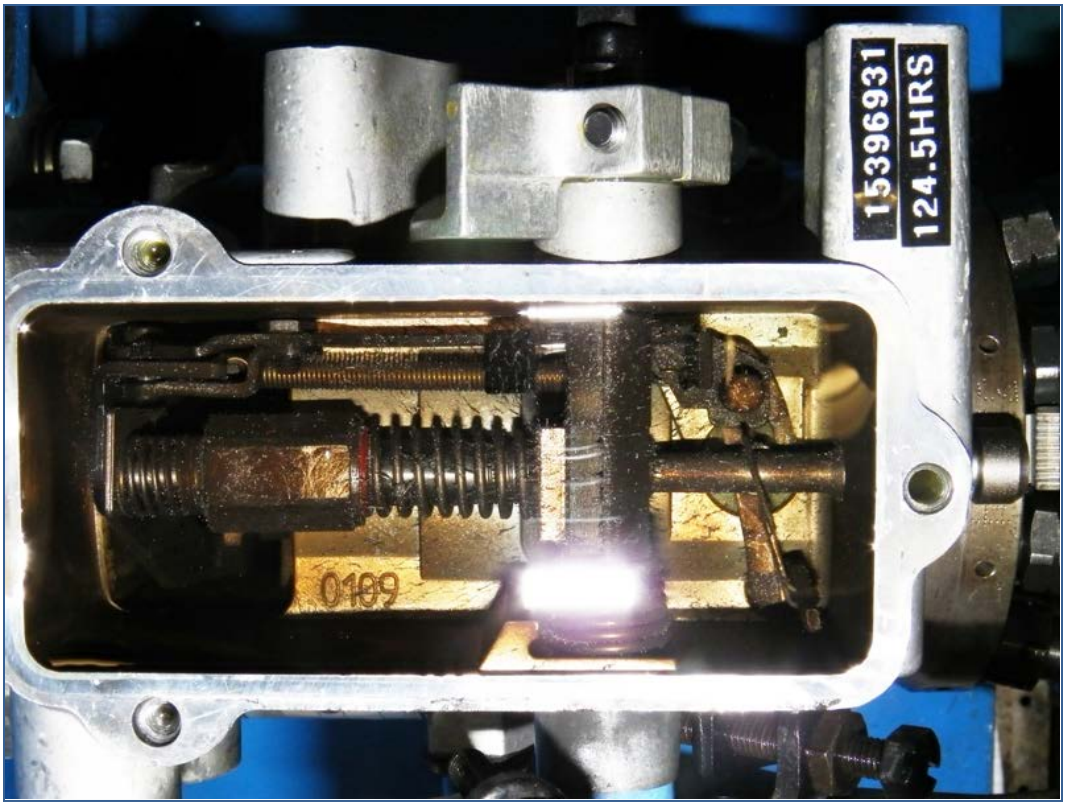


Figure 10. Test 5, Pump 1 (Operating Pump Removed from Testing) Linkage Debris

5.3.1 Test 5 Fuel Injection System Performance Observations

Test 5 with Jet A-1 fuel at 105°F fuel inlet temperature was terminated at 124.5-hours of operation with one fuel injection pump operational, and one seized. For pump SN15396931 there were 6 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed and fuelling quantities are noted as cc/1,000-strokes. Four of the deviations were injection timing variations at 350 rpm and 1,600 rpm engine speeds. At 350 rpm idle the timing was retarded 3.5° from the specification minimum. At 1,600 rpm full- power the timing was retarded over 2° from the specification minimum, and at 1,600 rpm low idle over 3° retarded. The 350 rpm low idle fuelling was 5-cc, 12-cc minimum, indicating poor idle or idle stall would occur. The fuel delivery at 900 rpm was 89-cc, with a specification maximum of 69.5-cc, likely to result in excessive smoke near peak torque. Although there are not any maximum delivery specifications at 1,600 rpm and 1,850 rpm, pump SN15396931 increased delivery substantially at those pump speeds. However the delivery at the 1,950 rpm governor cut-in speed was not compromised.

For fuel injection pump SN15396931 there was an average 1.0-mg decrease in transfer blade weight over the four blades, a 0.027-inch increase in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.935 (0=new, 5=fail). The increased Roller-to-Roller dimension is a direct cause of the increased fuel delivery seen at full-rack conditions. All eight fuel injectors passed the post test performance checks, likely due to the abbreviated test hours.

The fuel injection pump SN15396932 seized on the test stand. With the pump head and rotor seizure, post test calibration performance could not be determined.

For fuel injection pump SN15396932 there was also an average 10.4-mg decrease in transfer blade weight over the four blades, Roller-to-Roller dimension change could not be measured due to seizure, and an the averaged subjective wear rating was 2.5 (0=new, 5=fail). Likely wear debris from the transfer pump blades initiated the head and rotor seizure. In addition all fuel injectors passed the post test performance checks, due to the low test hours.

5.4 TEST 6, 8, AND 10 - JET A-1 WITH DCI-4A CI/LI ADDITIVE AT MAXIMUM LEVEL

Tests 6, 8, and 10 were conducted using Jet A-1 fuel additized with the MIL-PRF-25017 additive DCI-4A CI/LI, at the maximum allowable concentration of 22.5-mg/L, at temperatures of 105°F (40°C), 135°F (57°), and 170°F (77°C) for a targeted 1,000 pump stand hours.

5.4.1 Test 6 Fuel Injection System Performance Observations

Test 6 with Jet A-1 fuel treated with 22.5-mg/L DCI-4A, performed at 105°F fuel inlet temperature, completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15396935 there were 3 occurrences of post-test calibration parameters falling out of specification. The low idle injection quantity at 350 rpm was measured at 10-cc, where the specification has a 12-cc minimum. This would suggest poor idle stability or low idle speed with pump SN15396935. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum), and the delivery was 2-cc low at 200 rpm (58-cc minimum). The delivery loss at 900 rpm may reduce engine peak torque.

For fuel injection pump SN15396935 there was an average 4.2-mg decrease in transfer blade weight over the four blades, a 0.019-inch increase in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.370 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15396948 there were 4 occurrences of post-test calibration parameters falling out of specification. Two were minor variations that would not impact operability of an engine. The low idle injection quantity was measured at 8-cc/1,000-stroke, where the specification has a 12-cc/1,000-stroke minimum. This would suggest poor idle stability, or low idle speed pump SN15396948. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum); the delivery loss at 900 rpm may reduce engine peak torque.

For fuel injection pump SN15396948 there was also an average 4.3-mg increase in transfer blade weight over the four blades, a 0.001-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.587 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.4.2 Test 8 Fuel Injection System Performance Observations

Test 8 with Jet A-1 with 22.5-mg/L DCI-4A additive performed at 135°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15396951 there were 2 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed that would be one-half the engine speed and fuelling quantities are noted as cc/1,000-strokes. The low idle injection quantity at 350 rpm was measured at 9-cc, where the specification has a 12-cc minimum. A slight variation in low idle speed with pump SN15396951 may exist. Housing return flow at 1,000 rpm exceeded the maximum, indicative of increased housing pressure due to excess leakage from the high pressure section of the fuel injection pump.

For fuel injection pump SN15396951 there was an average 3.3-mg decrease in transfer blade weight over the four blades, a 0.0007-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.435 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15396952 there were 3 occurrences of post-test calibration parameters falling out of specification. Most were minor variations that would not impact operability of an engine. The low idle injection quantity was measured at 0-cc/1,000-stroke, where the specification has a 12-cc/1,000-stroke minimum. For pump SN15396952 an engine would stall coming down to idle. It is likely this engine would start, but then stall as idle speed is attained, unless the operator increased rack position. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum); the delivery loss at 900 rpm may have a minor impact on engine peak torque. Housing return flow at 1,000 rpm exceeded the maximum specification.

For fuel injection pump SN15396952 there was also an average 5.0-mg decrease in transfer blade weight over the four blades, a 0.001-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.370 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.4.3 Test 10 Fuel Injection System Performance Observations

Test 10 with Jet A-1 with 22.5-mg/L DCI-4A additive performed at 170°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15396955 there were 3 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed and fuelling quantities are cc/1,000-strokes. The low idle injection quantity at 350 rpm was measured at 17-cc, where the specification has a 16-cc maximum delivery. For pump SN15396955 an engine may have a surging, rough, or fast idle.

The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum). The housing return fuel flow at 1,000 rpm exceeded the maximum specification.

For fuel injection pump SN15396955 there was an average 1.7-mg increase in transfer blade weight over the four blades, a 0.0011-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.283 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15396956 there were 2 occurrences of post-test calibration parameters falling out of specification. The two deviations were minor variations that would not impact operability of an engine. The first was a 1-psi elevated transfer pump pressure at 1,000 rpm, and the second was a 0.5° retard of the 1,600 rpm low idle injection timing.

For fuel injection pump SN15396956 there was an average 3.6-mg increase in transfer blade weight over the four blades, a 0.0013-inch decrease in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.261 (0=new, 5=fail). All eight fuel injectors passed the post test injector performance checks.

5.5 TEST 7, 9, AND 11 - JET A-1 WITH NALCO 5403 CL/CI ADDITIVE AT MAXIMUM LEVEL

Tests 7, 9, and 11 were conducted using Jet A-1 fuel additized with MIL-PRF-25017 additive Nalco 5403 CI/LI at the 25-mg/L maximum allowable concentration at temperatures of 105°F (40°C), 135°F (57°), and 170°F (77°C) for a targeted 1,000 pump stand hours.

5.5.1 Test 7 Fuel Injection System Performance Observations

Test 7 with Jet A-1 fuel treated with 25-mg/L Nalco 5403, performed at 105°F fuel inlet temperature, completed 1000-hours of operation with both fuel injection pumps operational. For pump SN15396949 there were 4 occurrences of post-test calibration parameters falling out of specification, two of which were minor deviations not likely to impact engine performance. The fuel delivery at 900 rpm was 2.5-cc below specification (66.5-cc minimum), and the delivery was 1-cc low at 200 rpm (58-cc minimum).

For fuel injection pump SN15396949 there was an average 4.2-mg decrease in transfer blade weight over the four blades, a 0.007-inch increase in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.630 (0=new, 5=fail). Seven of eight fuel injectors passed the post test performance checks. The compromised injector failed the chatter and spray pattern tests.

For pump SN15396950 there were 4 occurrences of post-test calibration parameters falling out of specification. One was a minor timing variation that would not impact operability of an engine. The low idle injection quantity was measured at 7-cc/1,000-stroke, where the specification has a 12-cc/1,000-stroke minimum. This would suggest poor idle stability, or low idle speed pump SN15396950. The fuel delivery at 900 rpm was 2.5-cc below specification (66.5-cc minimum) and the delivery at 200 rpm was 3cc below the 58-cc minimum. The delivery at 200 rpm helps accelerate the engine from cranking speed to the idle speed against parasitic loads. A reduced 200 rpm delivery may cause an engine to stall after starting.

For fuel injection pump SN15396950 there was also an average 1.9-mg decrease in transfer blade weight over the four blades, a 0.039-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.435 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.5.2 Test 9 Fuel Injection System Performance Observations

Test 9 with Jet A-1 fuel treated with 25-mg/L Nalco 5403, performed at 135°F fuel inlet temperature, completed 1,000-hours of operation with both fuel injection pumps operational. Upon removal from the test stand pump SN15396953 revealed a failed driveshaft needle bearing. The failure of the needle bearing damaged the housing and driveshaft, so the post-test specification performance could not be performed.

For fuel injection pump SN15396953 there was an average 12.9-mg decrease in transfer blade weight over the four blades, a 0.0002-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.391 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15396954 there were 3 occurrences of post-test calibration parameters falling out of specification. Most were minor variations that would not impact operability of an engine. The low idle injection quantity was measured at 0-cc/1,000-stroke, where the specification has a 12-cc/1,000-stroke minimum. For pump SN15396954 an engine would stall coming down to idle. It is likely this engine would start, but then stall as idle speed is attained, unless the operator increased rack position. The fuel delivery at 1,825 rpm was 4-cc, substantially below the 33-cc specification minimum, indicating governor action is occurring at a lower pump speed. Housing return flow at 1,000 rpm exceeded the maximum specification, indicating a housing pressure increase due to internal leakage.

For fuel injection pump SN15396954 there was an average 4.5-mg increase in transfer blade weight over the four blades, a 0.0012-inch decrease in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.457 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

5.5.3 Test 11 Fuel Injection System Performance Observations

Test 11 with Jet A-1 fuel treated with 25-mg/L Nalco 5403, performed at 170°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15438592 there were 7 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed that would be one-half the engine speed. Fuelling quantities are noted as cc/1,000-strokes. One deviation was a minor timing variation likely to not impact operability of an engine. The low idle injection quantity at 350 rpm was measured at 19-cc, where the specification has a 16-cc maximum delivery. In addition the housing pressure at 350 rpm was 2-psi below the 8-psi minimum. For pump SN15396955 an engine may have a surging, rough, or fast idle. The 750 rpm shut-off delivery was 12-cc, compared to a 4-cc specification maximum; it is possible the engine could run-on after the ignition is turned off. The transfer pump pressure at 1,000 rpm was 55-psi, with a specification minimum of 60-psi. Low transfer pump pressure at 1,000 rpm could affect fuel metering and engine peak torque performance. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum) and the delivery at 200 rpm was 3cc below the 58-cc minimum.

For fuel injection pump SN15438592 there was an average 18.7-mg decrease in transfer blade weight over the four blades, a 0.0002-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.609 (0=new, 5=fail). All eight fuel injectors passed the post test performance checks.

For pump SN15438593 there were 6 occurrences of post-test calibration parameters falling out of specification. Three were minor timing variations that likely would not impact operability of an engine. The transfer pump pressure at 1,000 rpm, near peak torque, was 53-psi, with a specification minimum of 60-psi. Low transfer pump pressure at 1000 rpm could affect fuel metering and engine peak torque performance. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum) and the delivery at 200 rpm was 2cc below the 58-cc minimum. The delivery at 200 rpm helps accelerate the engine from cranking speed to the idle speed against parasitic loads.

For fuel injection pump SN15438593 there was also an average 10.6-mg decrease in transfer blade weight over the four blades, a 0.0019-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.761 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

5.6 TEST 12 – JET A-1 WITH INNOSPEC OLI-9070X COMMERCIAL DIESEL FUEL LUBRICITY IMPROVER AT 50-MG/L CONCENTRATION

Test 12 was conducted using Jet A-1 fuel additized with Innospec OLI-9070x commercial diesel lubricity improver at manufacturer's recommended minimum concentration of 50-mg/L at 105°F (40°C) temperature for a targeted 1,000 pump stand hours. The 50-mg/L concentration is twice the maximum concentration of the MIL-PRF-25017 additives. A brief study of the OLI-9070x additive in Jet A-1 suggested diminishing returns on effectiveness at higher concentrations.

5.6.1 Test 12 Fuel Injection System Performance Observations

Test 12 with Jet A-1 fuel with Innospec commercial diesel fuel additive at 105°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15438594 there was one occurrence of a post-test calibration parameter falling out of specification. The speeds noted are pump speed and fuelling quantities are noted as cc/1000-strokes. The low idle injection quantity at 350 rpm was measured at 20-cc, where the specification has a 16-cc maximum delivery. For pump SN15438594 an engine may have a surging, rough, or fast idle.

For fuel injection pump SN15438594 there was an average 1.1-mg increase in transfer blade weight over the four blades, a 0.0013-inch increase in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.717 (0=new, 5=fail). Six of the eight fuel injectors passed the post test performance checks. The two injectors that failed did not pass the leakage test, likely due to pintle seat condition.

For pump SN15438595 there were three occurrences of a post-test calibration parameters falling out of specification. The transfer pump pressure at 1000 rpm was 64-psi, with a specification maximum of 62-psi. At 1,000 rpm the housing return fuel flow also exceeded the maximum specification. It is likely the increased return flow is related to the elevated transfer pump pressure at 1,000 rpm. The low idle injection quantity at 350 rpm was measured at 10-cc, where the specification has a 12-cc minimum delivery. For pump SN15438595 an engine may have a rough idle.

For fuel injection pump SN15438595 there was also an average 1.2-mg decrease in transfer blade weight over the four blades, a 0.0008-inch Roller-to-Roller dimension increase, and an averaged subjective wear rating of 1.652 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

5.7 TEST 13 - JET A-1 WITH INNOSPEC OLI-9070X COMMERCIAL DIESEL FUEL LUBRICITY IMPROVER AT 50-MG/L CONCENTRATION

Test 13 was conducted using Jet A-1 fuel additized with Innospec OLI-9070x commercial diesel lubricity improver at manufacturer's recommended minimum concentration of 50-mg/L at 135°F (57°) temperature for a targeted 1,000 pump stand hours.

5.7.1 Test 13 Fuel Injection System Performance Observations

Test 13 with Jet A-1 fuel with Innospec commercial diesel fuel additive at 135°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15438596 there were 5 occurrences of post-test calibration parameters falling out of specification. The low idle injection quantity at 350 rpm was measured at 10-cc, where the specification has a 12-cc minimum. This would suggest poor idle stability or low idle speed with pump SN15438596. The fuel delivery at 900 rpm was 3.5-cc below specification (66.5-cc minimum), and the delivery was 3-cc low at 200 rpm (58-cc minimum). The delivery loss at 900 rpm may reduce engine peak torque, and the reduced 200 rpm delivery could affect the ramp to idle speed after starting. The delivery at 1,600 rpm was at the minimum, possibly effecting power and the timing advance was retarded 0.5° from specification minimum.

For fuel injection pump SN15438596 there was an average 0.6-mg increase in transfer blade weight over the four blades, a 0.0025-inch increase in Roller-to-Roller dimension, and an averaged subjective wear measurement of 2.227 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15438597 there were 5 occurrences of post-test calibration parameters falling out of specification. The transfer pump pressure at 1000 rpm was 65-psi, with a specification maximum of 62-psi. At 1,000 rpm the housing return fuel flow also exceeded the maximum specification. It is likely the increased return flow is related to the elevated transfer pump pressure at 1,000 rpm. The low idle injection quantity at 350 rpm was measured at 10-cc, where the specification has a 12-cc minimum. This would suggest poor idle stability or low idle speed with pump SN15438597. The fuel delivery at 900 rpm was 3.5-cc below specification (66.5-cc minimum), and the delivery was 2-cc low at 200 rpm (58-cc minimum). The delivery loss at 900 rpm may reduce engine peak torque, and the reduced 200 rpm delivery could affect the ramp to idle speed after starting.

For fuel injection pump SN15438597 there was also an average 6.6-mg increase in transfer blade weight over the four blades, a 0.0018-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.630 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.8 TEST 14 - JET A-1 WITH INNOSPEC OLI-9070X COMMERCIAL DIESEL FUEL LUBRICITY IMPROVER AT 50-MG/L CONCENTRATION

Test 14 was conducted using Jet A-1 fuel additized with Innospec OLI-9070x commercial diesel lubricity improver at manufacturer’s recommended minimum concentration of 50-mg/L at 170°F (77°C) temperature for a targeted 1,000 pump stand hours.

The pump stand was shut down for a fuel changeover at 750 hours of operation. When the test stand was restarted and ramping to the specified 1,700 rpm, the housing pressure on pump No. 1 dropped significantly. Fuel began spewing out of test stand gear box and the pump seized. Investigation revealed that the housing needle bearings had worn excessively creating friction and heat that disintegrated the red fluorosilicone and one of two black viton driveshaft seals. The oil reservoir was drained, cleaned and refilled. Test 14 was restarted and continued with the operational pump until the targeted 1,000-hours was attained. Figure 11 shows the scarred driveshaft assembly and the one remaining seal on pump No. 1. Figure 12 shows the pump body assembly with the damaged needle bearing race.

Figure 11. Drive Shaft Assembly Damage, Pump No. 1, Test 14

Figure 12. Housing Assembly Damage, Pump No.1, Test 14

5.8.1 Test 14 Fuel Injection System Performance Observations

Test 14 with Jet A-1 fuel treated with Innospec commercial diesel fuel additive performed at 170°F fuel inlet temperature, completed 750-hours of operation with fuel injection pump SN15438598. The test was terminated due to driveshaft needle bearing and driveshaft seal failures. Pump SN15438598 could not be installed on the calibration stand for post test specification checks.

For fuel injection pump SN15438598 there was an average 18.0-mg decrease in transfer blade weight over the four blades, a 0.0004-inch decrease in Roller-to-Roller dimension, and an averaged subjective wear measurement of 2.087 (0=new, 5=fail). All eight fuel injectors passed the post test performance checks.

Pump SN15438599 completed 1000-hours of operation. At the conclusion of testing there were 3 occurrences of post-test calibration parameters falling out of specification. The low idle injection quantity was measured at 2-cc/1000-stroke, where the specification is a 12-cc/1,000-stroke minimum. This would suggest poor idle stability or idle stall with pump SN15438599. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum), which may impact peak torque. The Full Rack advance at 1,600 rpm was 5.2°, compared to a maximum specification of 3.5° advance. Excess advance at 1,600 rpm could impact power, emissions, and efficiency.

For fuel injection pump SN15438599 there was also an average 16.7-mg decrease in transfer blade weight over the four blades, a 0.0003-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.761 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.9 TEST 15 – FT-SPK WITHOUT CI/LI ADDITIVE

Test 15 was conducted using neat SPK fuel without any lubricity improver at fuel temperature of 105°F (40°C) for a targeted 1,000 pump stand hours. Pump No 1 seized 35 minutes (0.59-hours) into operation causing the driveshaft to shear, immediately terminating testing. Injected fuel delivery had increased about 8% from initiation of testing; therefore, pump seizure was not anticipated. Test 15 was continued with the operational pump. At 48.2-hours the injected fuel delivery had increased by 28%, and the stand was shut down to remove the governor assembly top and side covers in order to inspect the visible components for wear. The governor assembly was free of debris; however one of the rollers visible through the side cover had a visible wear scar. Upon re-starting the test, the fuel injection pump rotor seized, terminating the test. Subsequent teardown verified severe wear on the rollers and wear at the contact between the roller shoes and leaf spring.

Prior testing with unadulterated synthetic aviation kerosene fuels made, with by various processing methods and hydrocarbon sources, have indicated the synthetic fuels may have poor fuel lubricity, and cause premature failure in rotary fuel injection pumps. These results confirm the poor lubricity performance previously seen with untreated synthetic kerosene fuels.

5.9.1 Test 15 Fuel Injection System Performance Observations

Test 15 with unadulterated Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK) performed at 105°F fuel inlet temperature completed 0.59-hours of operation with fuel injection pump SN15438603 before seizure of the head and rotor. Due to the seized head and rotor post-test delivery characteristics could not be performed.

For fuel injection pump SN15438603 there was an average 18.9-mg decrease in transfer blade weight over the four blades, Roller-to-Roller dimensional change not determined, and an averaged subjective wear measurement of 1.761 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks, due to the short test interval.

Fuel injection pump SN15438885 was operational for 48-hours on the test stand before seizure of the head and rotor occurred. Due to the seized head and rotor post-test delivery characteristics could not be performed.

For fuel injection pump SN15438885 there was also an average 15.0-mg decrease in transfer blade weight over the four blades, indeterminable Roller-to-Roller dimension change, and an averaged subjective wear rating of 1.891 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.10 TEST 16 – FT-SPK WITH DCI-4A CI/LI ADDITIVE AT MAXIMUM LEVEL

Test 16 was conducted using FT-SPK with DCI-4A CI/LI at the maximum concentration level qualified in MIL-PRF-25017 of 22.5-mg/L at 105°F (40°C) for a targeted 1,000 pump stand hours.

5.10.1 Test 16 Fuel Injection System Performance Observations

Test 16 with FT-SPK treated with 22.5-mg/L DCI-4A, performed at 105°F fuel inlet temperature, completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15438886 there were 2 occurrences of post-test calibration parameters falling out of specification. One deviation was a 0.5° timing retard at 350 rpm low idle, not likely to impact operability of an engine. Housing return fuel flow at 1,000 rpm exceeded the maximum specification, likely due to increased housing pressure from internal pump leakage.

For fuel injection pump SN15438886 there was an average 4.7-mg decrease in transfer blade weight over the four blades, a 0.0003-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.761 (0=new, 5=fail). All eight fuel injectors failed the post test performance check leakage tests.

For pump SN15438887 there were 2 occurrences of post-test calibration parameters falling out of specification. Both were minor variations that would not impact operability of an engine. The injection quantity measured at 900 rpm was 0.5-cc below the 66.5-cc minimum. The full-rack injection timing advance at 1,600 rpm exceeded the maximum advance by 0.23 degrees.

For fuel injection pump SN15438887 there was an average 5.3-mg decrease in transfer blade weight over the four blades, no change in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.826 (0=new, 5=fail). Five fuel injectors failed the post test performance leakage checks.

5.11 TEST 17 – FT-SPK WITH DCI-4A CI/LI ADDITIVE AT MAXIMUM LEVEL

Test 17 was conducted using FT-SPK with DCI-4A CI/LI at the maximum concentration level qualified in MIL-PRF-25017 of 22.5-mg/L at 135°F (57°C) for a targeted 1,000 pump stand hours.

5.11.1 Test 17 Fuel Injection System Performance Observations

Test 17 with FT-SPK treated with 22.5-mg/L DCI-4A, performed at 135°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15438888 there were 2 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed and fuelling quantities are cc/1,000-strokes. The low idle injection quantity at 350 rpm was measured at 6-cc, where the specification has a 12-cc minimum delivery. For pump SN15438888 an engine may have a rough idle or idle stall. The fuel delivery at 900 rpm was 1.5-cc below specification (66.5-cc minimum).

For fuel injection pump SN15438888 there was an average 16.5-mg increase in transfer blade weight over the four blades, a 0.0006-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.935 (0=new, 5=fail). Five fuel injectors failed the post test leakage performance checks.

For pump SN15438889 there was 1 occurrence of post-test calibration parameters falling out of specification. The low idle injection quantity at 350 rpm was measured at 4-cc, where the specification has a 12-cc minimum delivery. For pump SN15438889 an engine may have a rough idle or idle stall.

For fuel injection pump SN15438889 there was an average 16.8-mg increase in transfer blade weight over the four blades, a 0.0002-inch decrease in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.957 (0=new, 5=fail). All eight fuel injectors passed the post test injector performance checks.

5.12 TEST 18 – FT-SPK WITH DCI-4A CI/LI ADDITIVE AT MAXIMUM LEVEL

Test 18 was conducted using FT-SPK with DCI-4A CI/LI at the maximum concentration level qualified in MIL-PRF-25017 of 22.5-mg/L at 170°F (77°C) for a targeted 1000 pump stand hours.

5.12.1 Test 18 Fuel Injection System Performance Observations

Test 18 with FT-SPK treated with 22.5-mg/L DCI-4A, performed at 170°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15438891 there were 2 occurrences of post-test calibration parameters falling out of specification. One deviation was a minor 0.5° retard of injection timing advance at 350 rpm low idle that likely would not impact operability of an engine. Housing return fuel flow at 1,000 rpm exceeded the maximum specification, likely due to increased housing pressure from internal pump leakage.

For fuel injection pump SN15438891 there was an average 11.5-mg decrease in transfer blade weight over the four blades, a 0.003-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.630 (0=new, 5=fail). Seven fuel injectors passed the post test performance checks. The failed injector did not pass the leakage, chatter, or spray tests.

For pump SN15438892 there were 2 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed and fuelling quantities are noted as cc/1,000-strokes. One was a minor timing variation in the 1600 rpm face cam advances that likely would not impact operability of an engine. The low idle injection quantity at 350 rpm was measured at 27-cc, where the specification has a 16-cc maximum delivery. For pump SN15438892 an engine may have a surging, rough, or fast idle.

For fuel injection pump SN15438892 there was also an average 3.1-mg decrease in transfer blade weight over the four blades, a 0.0010-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 1.630 (0=new, 5=fail). Seven fuel injectors passed the post test performance checks. The failed injector did not pass the leakage, chatter, or spray tests.

5.13 TEST 19 – 50/50 FT-SPK/JET A-1 WITH DCI-4A CI/LI ADDITIVE AT MINIMUM LEVEL

Test 19 was conducted using a 50/50 blend of FT-SPK and Jet A-1 fuel additized with DCI-4A CI/LI at the minimum concentration level qualified in MIL-PRF-25017 of 9-mg/L at 105°F (40°C) for a targeted 1,000 pump stand hours. The concentration of additive was altered from the original scope of work to represent the possible worst case fuel seen in the field, a 50/50 blend of Jet A-1 and a low lubricity synthetic aviation kerosene with the minimum additive present. The DCI-4A additive was chosen because it appeared to offer slightly better wear protection than the other MIL-PRF-25017 added evaluated.

5.13.1 Test 19 Fuel Injection System Performance Observations

Test 19 with 50/50 FT-SPK/Jet A-1 blend treated with 9-mg/L DCI-4A, performed at 105°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15442444 there was one occurrence of a post-test calibration parameter falling out of specification. The speeds noted are pump speed and fuelling quantities are noted as cc/1,000-strokes. The high idle injection quantity at 1,950 rpm was measured at 61cc, where the specification has a 15-cc maximum delivery. For pump SN15442444 an engine would have a compromised over-speed protection as the governor action is not cutting off the fuel flow properly.

For fuel injection pump SN15442444 there was an average 7.9-mg decrease in transfer blade weight over the four blades, not any change in Roller-to-Roller dimension, and an averaged subjective wear measurement of 1.739 (0=new, 5=fail). Seven of the eight fuel injectors passed the post test performance checks. The injector that failed did not pass the tip leakage test, likely due to pintle seat condition.

For pump SN15442445 there were two occurrences of a post-test calibration parameters falling out of specification. The transfer pump pressure at 1,000 rpm was 63-psi, with a specification maximum of 62-psi. The low idle injection timing advance at 350 rpm was 0.75° retarded from the 3.5° minimum advance specification. For pump SN15442445 an engine may experience a rough idle.

For fuel injection pump SN15442445 there was not any change in transfer blade weight over the four blades, a 0.0001-inch Roller-to-Roller dimension increase, and an averaged subjective wear rating of 1.804 (0=new, 5=fail). Six of the eight fuel injectors failed the post test performance checks, due to tip leakage.

5.14 TEST 20 – 50/50 FT-SPK/JET A-1 WITH DCI-4A CI/LI ADDITIVE AT MINIMUM LEVEL

Test 20 was conducted using a 50/50 blend of FT-SPK and Jet A-1 fuel additized with DCI-4A CI/LI at minimum concentration of 9 mg/L at temperatures of 135°F (57°C) for a targeted 1,000 pump stand hours.

5.14.1 Test 20 Fuel Injection System Performance Observations

Test 20 with 50/50 FT-SPK/Jet A-1 blend treated with 9-mg/L DCI-4A, performed at 135°F fuel inlet temperature completed 1,000-hours of operation with both fuel injection pumps operational. For pump SN15442663 there were 6 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed and fuelling quantities are noted as cc/1000-strokes. The low idle injection quantity at 350 rpm was measured at 46-cc, where the specification has a 16-cc maximum. Also at 350 rpm was a 1.8° retard of the injection timing from the minimum advance. This would suggest poor idle stability or a fast idle speed with pump SN15442663. All four full-rack fuel injection pump parameters affecting delivery at 1,600 rpm were out of specification, including delivery and timing values for the face cam. The 1,600 rpm delivery was 44-cc, with a 59-cc minimum specification, and the timing advance maximum was exceeded. Engine peak power would impacted by the 1,600 rpm fuel injection pump delivery characteristic changes.

For fuel injection pump SN15442663 there was an average 1.1-mg increase in transfer blade weight over the four blades, not any change in Roller-to-Roller dimension, and an averaged subjective wear measurement of 2.087 (0=new, 5=fail). In addition all fuel injectors passed the post test performance checks.

For pump SN15442664 there were 4 occurrences of post-test calibration parameters falling out of specification. The low idle injection quantity at 350 rpm was measured at 24-cc, where the specification has a 16-cc maximum. Also at 350 rpm was a 0.5° retard of the injection timing from the minimum advance. This would suggest poor idle stability or a fast idle speed with pump SN15442664. Two full-rack fuel injection pump parameters affecting delivery at 1600 rpm were out of specification. The 1,600 rpm delivery was 53-cc, with a 59-cc minimum specification and the timing advance maximum was exceeded. Engine peak power would impacted by the 1,600 rpm fuel injection pump delivery characteristic changes.

For fuel injection pump SN15442664 there was also an average 4.3-mg decrease in transfer blade weight over the four blades, a 0.0001-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 2.174 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.15 TEST 21 - 50/50 FT-SPK/JET A-1 WITH DCI-4A CI/LI ADDITIVE AT MINIMUM LEVEL

Test 21 was conducted using a 50/50 blend of FT-SPK and Jet A-1 fuel additized with DCI-4A CI/LI at minimum concentration of 9 mg/L at temperatures of 170°F (77°C) for a targeted 1,000 pump stand hours. At 372 hours into the test, pump No.2 displayed a notable drop (approx) 25% in the fuel moving average. The test stand was shut down and the governor assembly top cover removed from the pump to inspect for excessive wear. Heavy metal shavings were seen in the solenoid assembly and the pump was removed from the stand to prevent rotor seizure. Test 21 was continued with the operational pump No. 1. The test stand was stopped at 418 hours into the test when the remaining pump became very noisy due to drive tang wear and the fuel moving average had dropped significantly. Figure 13 presents the governor assembly from Pump No. 1 showing heavy wear debris on the linkages. Figure 14 reveals excessive heavy drive tang wear, the associated heavy rotor drive slot wear for Pump No.2 is shown in Figure 15, and the rotor governor weight cage drive plate wear and fractures are seen in Figure 16.

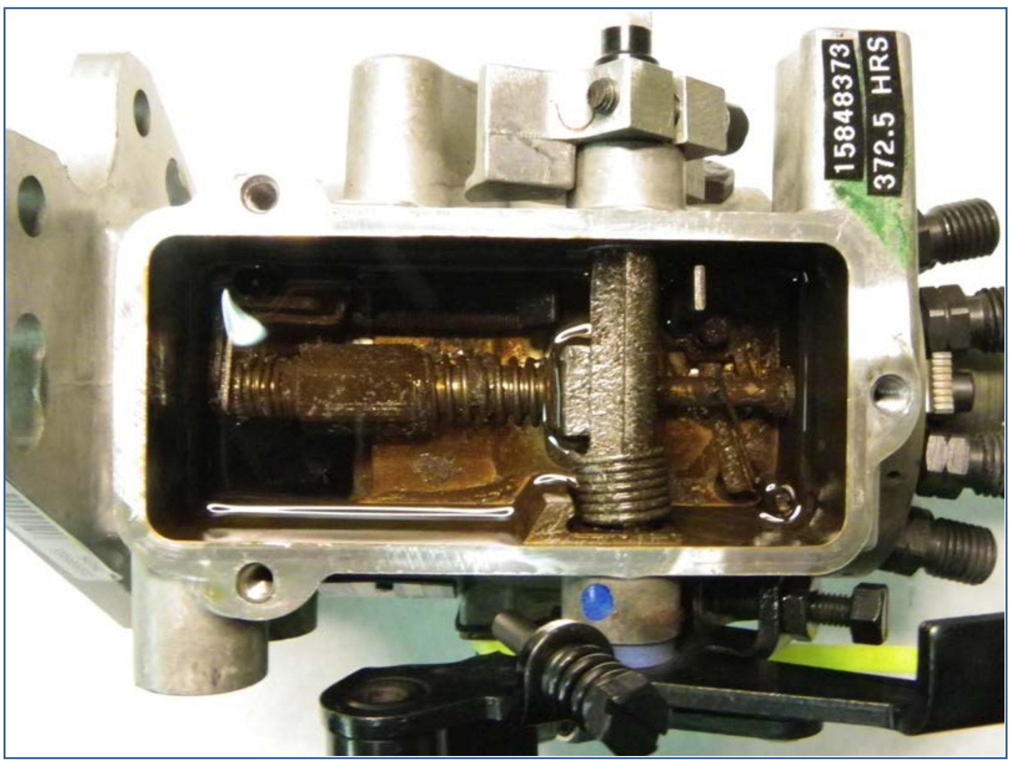


Figure 13. Wear Debris, Pump No. 1, Test 21

Figure 14. Heavy Drive Tang Wear, Pump No. 2, Test 21

Figure 15. Rotor Drive Slot Heavy Wear, Pump No. 2, Test 21

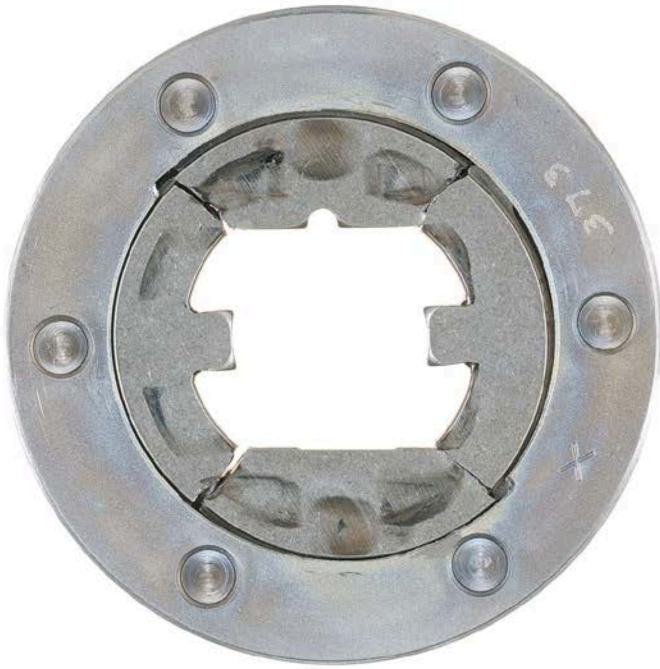


Figure 16. Broken Rotor Governor Weight Cage Drive Plate, Pump No. 2, Test 21

5.15.1 Test 21 Fuel Injection System Performance Observations

Test 21 with 50/50 FT-SPK/Jet A-1 blend treated with 9-mg/L DCI-4A, performed at 170°F fuel inlet temperature completed 418-hours of operation with fuel injection pump SN15848225. The test was terminated due to injected delivery variations on the test stand and excessive noise. Inspection by removal of the top cover revealed wear debris, thus it was felt test continuation could promote seizure and the post-test flow determinations would be indeterminable. At the conclusion of testing there were 4 occurrences of post-test calibration parameters falling out of specification. The low idle injection quantity was measured at 4-cc/1,000-stroke, where the specification is a 12-cc/1,000-stroke minimum, and the injection timing advance retarded 2.5° from the 3.5° minimum at the 350 rpm low idle. This would suggest poor idle stability or idle stall with pump SN15848225. The fuel delivery at 900 rpm was 1.5-cc above specification (69.5-cc maximum). The face cam advance at 1,600 rpm retarded 1.6°, compared to a minimum specification of 5.25° face cam timing advance. During teardown of pump SN15848225 there was noted excessive drive tang and drive slot wear, inducing considerable backlash in the pump drive, and likely the cause of the excessive noise.

For fuel injection pump SN15848225 there was an average 2.3-mg decrease in transfer blade weight over the four blades, a 0.0029-inch increase in Roller-to-Roller dimension, and an averaged subjective wear measurement of 2.130 (0=new, 5=fail). All eight fuel injectors passed the post test performance checks.

Pump SN15848373 completed 372-hours of operation. The test was terminated due to injected delivery variations on the test stand and excessive noise. Inspection by removal of the top cover revealed wear debris. At the conclusion of testing there were 11 occurrences of post-test calibration parameters falling out of specification. The speeds noted are pump speed and fuelling quantities are noted as cc/1,000-strokes. The low idle injection quantity at 350 rpm was measured at 46-cc, where the specification has a 16-cc maximum. Also at 350 rpm the housing pressure was 4-psi below the minimum specification. Low housing pressure can impact timing. These results would suggest poor idle stability or a fast engine idle speed with pump SN15848373. The fuel delivery at 900 rpm was 13.5-cc below specification (66.5-cc minimum), which may impact engine peak torque. All four full-rack fuel injection pump parameters affecting delivery at 1,600 rpm were out of specification, including delivery and timing values for the face cam. The 1,600 rpm delivery was 49-cc, with a 59-cc minimum specification, and the timing advance maximum was exceeded. Engine peak power would impacted by the 1600 rpm fuel injection pump delivery characteristic changes. The high idle injection quantity at 1950 rpm was measured at 46cc, where the specification has a 15-cc maximum delivery. For pump SN15848373 an engine would have a compromised over-speed protection as the governor action would not cut-off the fuel flow properly. The fuel delivery at 200 rpm was 46-cc, a full 12-cc below the 58-cc minimum. The delivery at 200 rpm helps accelerate the engine from cranking speed to the idle speed against parasitic loads. A reduced 200 rpm delivery may cause an engine to stall after starting. The fuel delivery at the cranking-speed of 75 rpm was 34-cc, (3-cc below the 37-cc minimum), and the cranking speed transfer pump pressure was 1-psi below the minimum. The 75 rpm cranking speed delivery performance for pump SN15848373 could result in an engine that will not start. During teardown of pump SN15848373 there was noted excessive drive tang and drive slot wear, inducing considerable backlash in the pump drive. The governor weight cage drive plate was also broken in four places, the combination of the governor drive plate failure and driveshaft backlash were likely the cause of the excessive noise.

For fuel injection pump SN15848373 there was also an average 1.1-mg decrease in transfer blade weight over the four blades, a 0.0097-inch reduction in Roller-to-Roller dimension, and an averaged subjective wear rating of 2.630 (0=new, 5=fail). All fuel injectors passed the post test performance checks.

5.16 SUMMARY OF TEST RESULTS

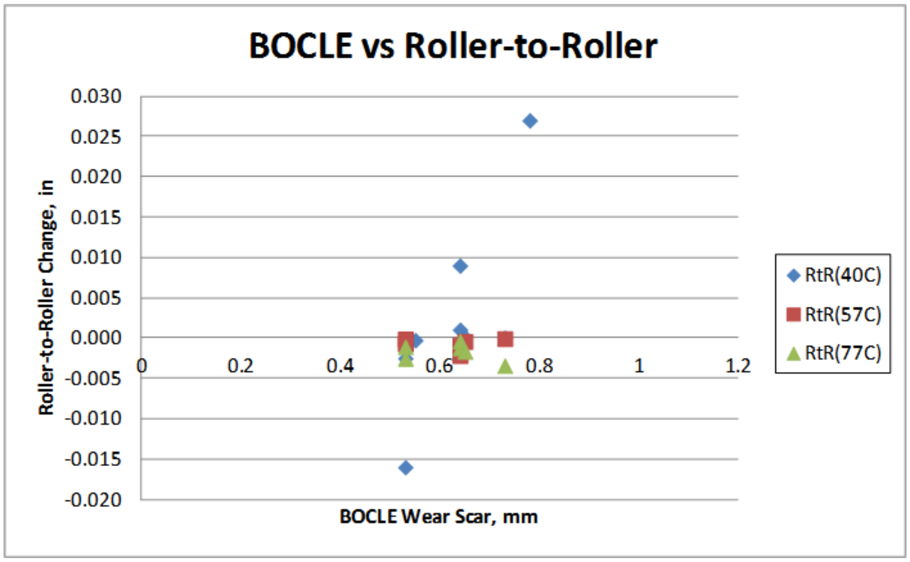
A summary of the tests conducted in this program is included as Table 6 . Included in the table is a comparison of bench lubricity tests and assessment of fuel related impacts on wear of the fuel injection pump. The assessments of wear are based on Roller-to-Roller dimensional change, transfer pump blade weight change, and the subjective wear rating of the test components. The tabled wear results are based on the average for both of the pumps that performed each test, for each parameter. A majority of the pumps completed 1,000 hours of operation; however there is wear that may occur within the fuel injection pump that could cause the pump to perform out of specification. During the calibration checks there are combinations of 22-parameters evaluated at different pump speeds that may include delivery, fuel pressure, or timing. The instances where the fuel injection pump performance was altered, have been discussed in the previous sections for each pump that performed each test.

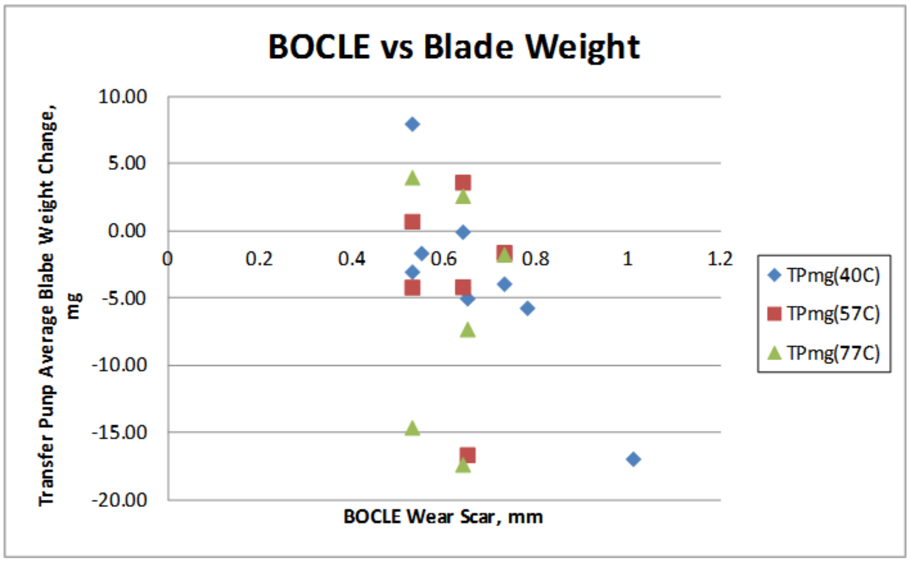
Based on the review of the pump specification checks for all testing, several recurring performance demerits were noted. For virtually all fuels, including DF-2, after 1,000-hours of operation a large number of fuel injection pumps exhibited compromised low idle delivery characteristics. Most of the compromised would result in rough idle, fast or slow idle, surging, or outright idle stall. Several of the fuel injection pumps exhibited compromised governor action for engine over-speed protection; some the cut-out speed started at lower engine speed, and one pump over-fueled at the cut-out speed. Several pumps had delivery characteristics near the peak torque and rated power speeds that could reduce peak torque and rated power. Only one fuel injection pump exhibited cranking delivery reductions that would impact engine starting.

Table 6. Summarized Bench Wear Tests and Rotary Pump Wear Evaluations

Fuel	BOCLE, mm	SLWT, grams	HFRR, mm	Roller-to-Roller Dimension Change, in. (40°C)	Transfer Pump Blade Weight Change, mg (40°C)	Subjective Wear Rating (40°C)	Roller-to-Roller Dimension Change, in. (57°C)	Transfer Pump Blade Weight Change, mg (57°C)	Subjective Wear Rating (57°C)	Roller-to-Roller Dimension Change, in. (77°C)	Transfer Pump Blade Weight Change, mg (77°C)	Subjective Wear Rating (77°C)
ULSD Grade 2	0.53	5500	0.294	-0.0025	7.98	1.109	-0.0001	0.71	1.141	-0.0025	3.9875	1.0978
ULSD Grade 2 (Clay Treated)	0.55	4400	0.640	-0.0003	-1.65	1.554						
Jet A-1	0.78	1800	0.603	0.0270	-5.73	2.217						
Jet A-1 + QPL1(maximum)	0.64	2500	0.653	0.0090	-4.23	1.478	-0.0008	-4.16	1.402	-0.0012	2.6219	1.2717
Jet A-1 + QPL2(maximum)	0.53	2200	0.664	-0.0160	-3.04	1.533	-0.0007	-4.19	1.424	-0.0011	-14.6156	1.6848
Jet A-1 + CDA(minimum)	0.64	2450	0.710	0.0011	-0.07	1.685	-0.0021	3.62	1.929	-0.0003	-17.3594	1.9239
FT-SPK	1.01	1200	0.840		-16.95	1.826						
FT-SPK + QPL1(maximum)	0.65	1850	0.800	0.0001	-5.02	1.793	-0.0004	-16.65	1.946	-0.0016	-7.2969	1.6304
FT-SPK/Jet A-1 + QPL1(minimum)	0.73	2100	0.681	0.0000	-3.93	1.772	0.0000	-1.61	2.130	-0.0034	-1.7375	2.3804

The fuel injection pump test stand wear assessment data for each test condition are plotted against the fuel lubricity bench test wear results. The ASTM D5001 BOCLE data for each test fuel is plotted against the three pump test wear criteria and presented in Figure 17. The pre-test BOCLE wear scar values are plotted in Figure 17 against the two pump average Roller-to-Roller dimension change, the eight blade average transfer pump blade weight change, and the two pump average subjective wear rating at each fuel inlet temperature. The Roller-to-Roller dimension change data at 40°C suggests that at increased BOCLE wear scars, low lubricity fuel, results in a larger dimensional change. The elevated temperature tests do not show the same relationship with the BOCLE data for Roller-to-Roller dimension change. The blade weight change comparison for the BOCLE data, although quite scattered does suggest that increased BOCLE values results in increased blade weight change. The 40°C data again appear to show a stronger trend with less scatter, due to more tests that were performed at 40°C. Of the three wear assessment variables in Figure 17, the subjective wear ratings appear to show a strong trend of increased wear rating with low lubricity fuels, larger BOCLE values, at all test temperatures.





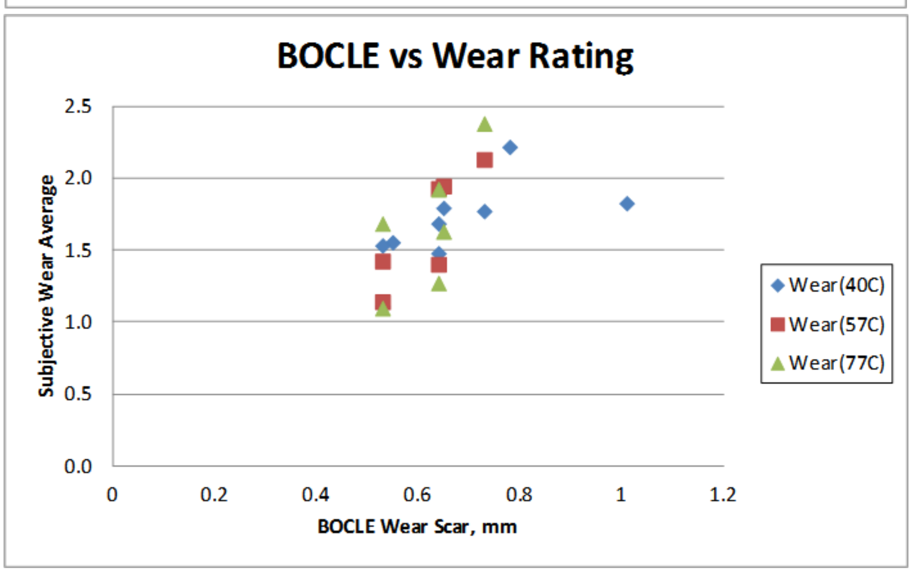


Figure 17. BOCLE Wear Scar versus Wear Parameters and Fuel Temperature

The ASTM D6079 Scuffing Load Wear Test (SLWT) data for each test fuel are plotted against the three pump test wear criteria and presented in Figure 18. The pre-test SLWT loads values are plotted in Figure 18 against the two pump average Roller-to-Roller dimension change, the eight blade average transfer pump blade weight change, and the two pump average subjective wear rating at each fuel inlet temperature. The Roller-to-Roller dimension change data at 40°C trends towards increased SLWT loads, good lubricity fuels, results in a less dimensional change. The elevated temperature tests do not show the same relationship with the SLWT data for Roller-to-Roller dimension change. The blade weight change comparison for the SLWT data, although quite scattered does suggest that increased fuel SLWT loads results in decreased blade weight change. The 40°C again appears to show a stronger trend with less scatter, due to more tests that were performed at 40°C. Of the three wear assessment variables in Figure 18, the subjective wear ratings appear to show a strong trend of increased wear with low lubricity fuels, smaller SLWT loads, at all test temperatures.

The ASTM D6078 HFRR fuel lubricity data for each test fuel are plotted against the three pump test wear criteria and presented in Figure 19. The pre-test HFRR wear scar values are plotted in Figure 19 against the two pump average Roller-to-Roller dimension change, the eight blade average transfer pump blade weight change, and the two pump average subjective wear rating at each fuel inlet temperature. The Roller-to-Roller dimension change data do not show a strong relationship with the HFRR wear scar data for any fuel temperature. The blade weight change comparison for the HFRR data, although quite scattered does suggest that increased HFRR wear scars result in increased blade weight change at all temperatures. The 40°C again appears to show a stronger trend with less scatter, due to more tests that were performed at 40°C. Of the three wear assessment variables in Figure 19, the subjective wear ratings appear to show a slight trend of increased wear with low lubricity fuels, larger HFRR values, at all test temperatures.

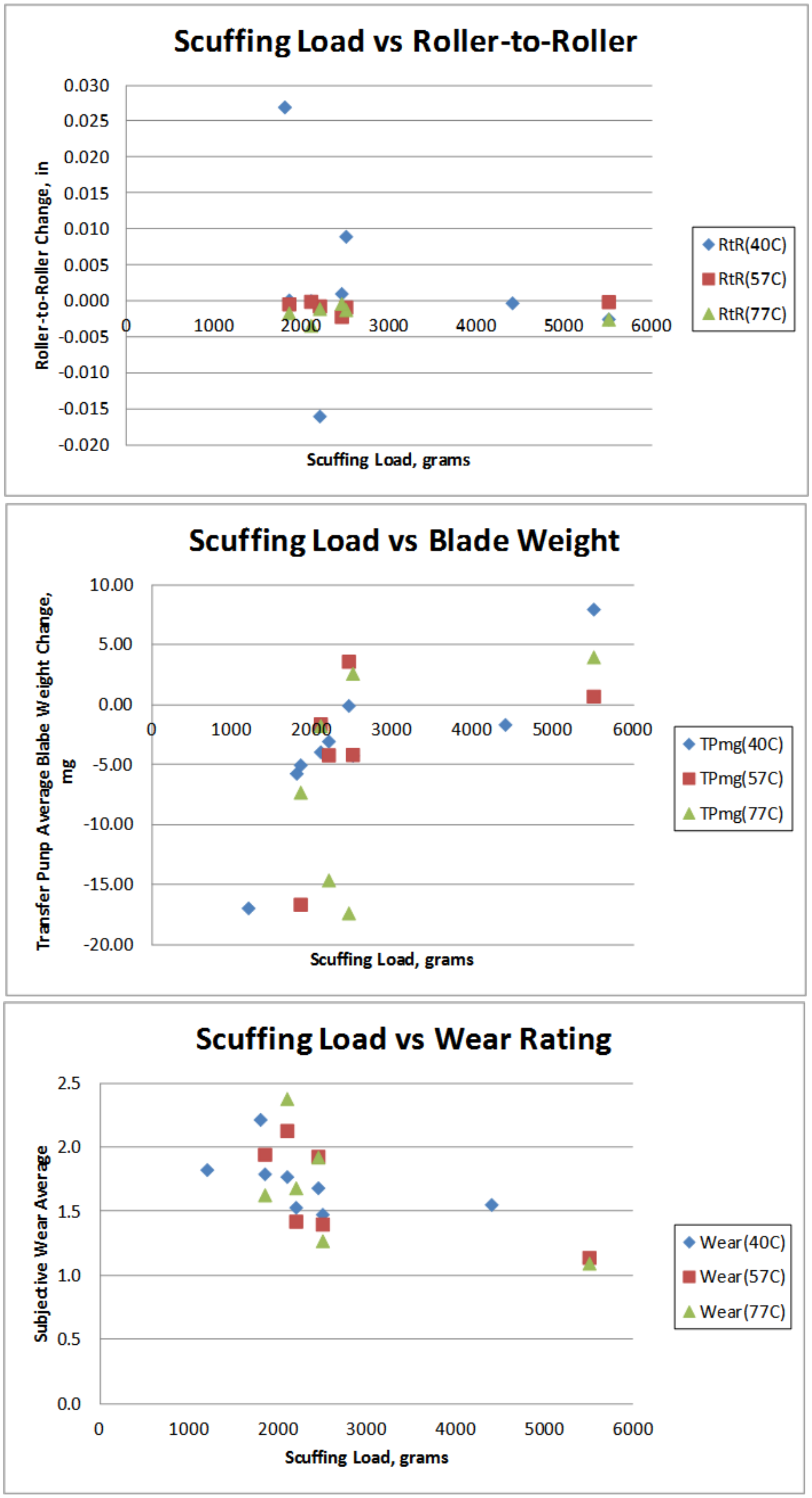


Figure 18. Scuffing Load versus Wear Parameter and Fuel Temperature

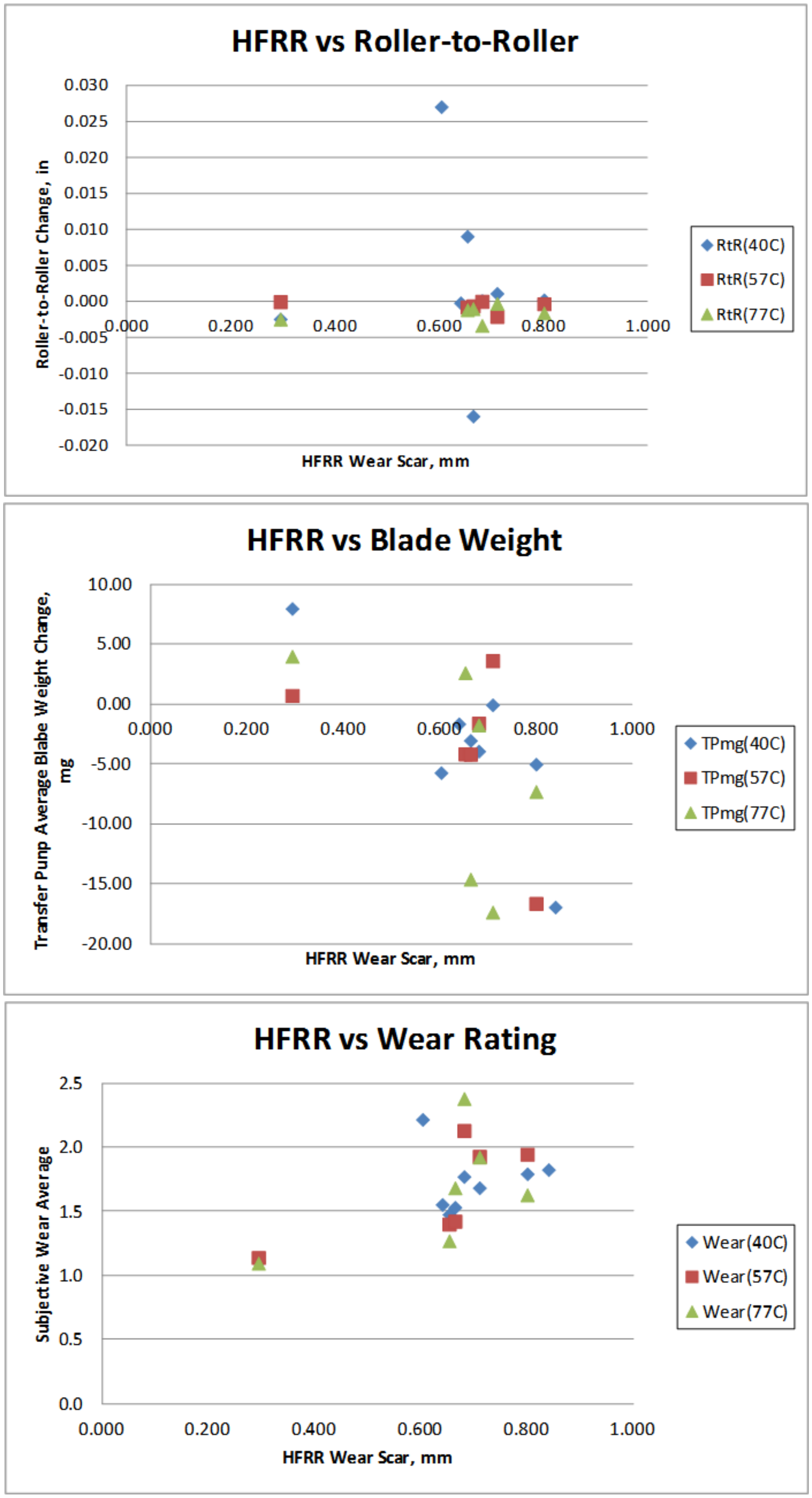


Figure 19. HFRR Wear Scar versus Wear Parameter and Fuel Temperature

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the data generated in this Stanadyne rotary fuel injection pump study the following conclusions regarding diesel fuel, aviation and alternative aviation kerosene fuels and blends thereof, and the effectiveness of Corrosion Inhibitor/Lubricity Improver (CI/LI) additives can be made.

- Some detrimental effects on fuel injection pump specification performance was observed for diesel fuel after 1,000-hours of operation.
- Clay Treated Diesel fuel revealed greater detrimental impacts on pump performance as compared to ULSD (not clay treated).
- Jet A-1 aviation kerosene fuel WITHOUT any CI/LI Additives Should NOT be Used in rotary, fuel-lubricated, fuel injection pumps.
- FT-SPK fuel unblended and WITHOUT any CI/LI Additives Should NOT be Used in rotary, fuel-lubricated, fuel injection pumps.
- CI/LI Additives greatly Improve Durability of both Jet A-1 fuel and the alternative aviation fuel FT-SPK at relatively low concentrations. All additives showed substantial improvements in fuel injection pump durability when blended with aviation kerosene fuel.
- MIL-PRF-25017 Additives perform better in aviation kerosene fuels than a Commercial Diesel Fuel additive, and at lower concentrations.
- MIL-PRF-25017 Additive DCI-4A performed slightly better than the other additives evaluated.
- The lubricity bench tests ASTM D6079 SLWT followed by the ASTM D5001 BOCLE, reveal general trends for predicting wear assessments at all test temperatures and all test fuels.
- The ASTM D6078 HFRR data appears more scattered, as the HFRR data for the test fuel set has a narrow range.

Based on the bench lubricity test results, and the fuel injection pump component wear assessments the following recommendations are being made.

- The MIL-PRF-25017 MAXIMUM effective concentration for the CI/LI additive DCI-4A, 22.5 mg/L, appears to offer ADEQUATE protection for rotary fuel injection pumps at fuel inlet temperatures up to 170°F (77°C).
    - Jet A-1 and the alternative aviation kerosene both displayed improved rotary fuel injection pump durability with the DCI-4A additive at the maximum effective concentration.
- The MIL-PRF-25017 maximum effective concentration for the CI/LI additive Nalco 5403, 25 mg/L, appears to offer adequate protection for rotary fuel injection pumps at fuel inlet temperatures up to 135°F (57°C) with Jet A-1 fuel. Additive effectiveness with an alternative aviation kerosene was not determined.
- The commercial diesel fuel CI/LI additive Innospec OLI-9070x appears to offer adequate protection for rotary fuel injection pumps at fuel inlet temperatures up to 135°F (57°C) with Jet A-1 fuel. Additive effectiveness with an alternative aviation kerosene was not determined.
- The MIL-PRF-25017 MINIMUM effective concentration for the CI/LI additive DCI-4A, 9-mg/L, offers INADEQUATE protection for rotary fuel injection pumps at 170°F (77°C) fuel inlet temperatures with the 50/50 Jet A-1/alternative aviation fuel blend.
- It is recommended for continuous operations in elevated temperature environments, the maximum treatment rate of MIL-PRF-25017 additives should be utilized in aviation kerosene fuel in order to protect rotary fuel injection pumps.

APPENDIX A

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Certification 2007 Diesel
Test Number: C4T1-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Certification 2007 Diesel
Test Fuel ID: AF 7469
Test Temperature: 40°C (104°F)
Test Number: C4T1-40-1000
Start of Test Date: June 23, 2010
End of Test Date: September 2, 2010
Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure 1.

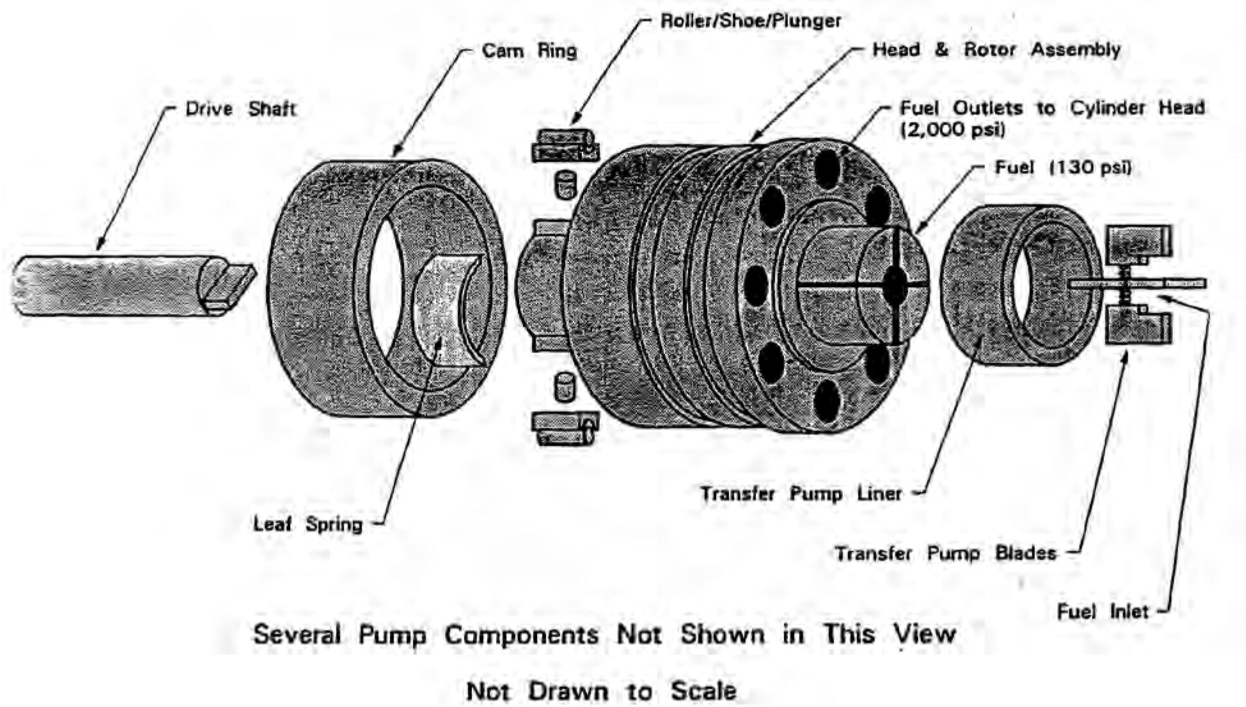


Figure A-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table A-1.

Table A-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table A-2.

Table A-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	2.38
FLO_R	Injected Flow-rate [mL/min]	841.70	12.44
FUELIN_P	Fuel Inlet Pressure [psig]	3	0.09
TRNS_P_R	Transfer Pump Pressure [psig]	79.6	.55
HSG_P_R	Pump Housing Pressure [psig]	10.6	.51
RTRN_T_R	Fuel Return Temperature [°C]	50.85	1.27
FUEL_T	Fuel Tank Temperature [°C]	30.4	1.32
FUELIN_T	Fuel Inlet Temperature [°C]	40	0.`38

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure A-2 through Figure A-4.

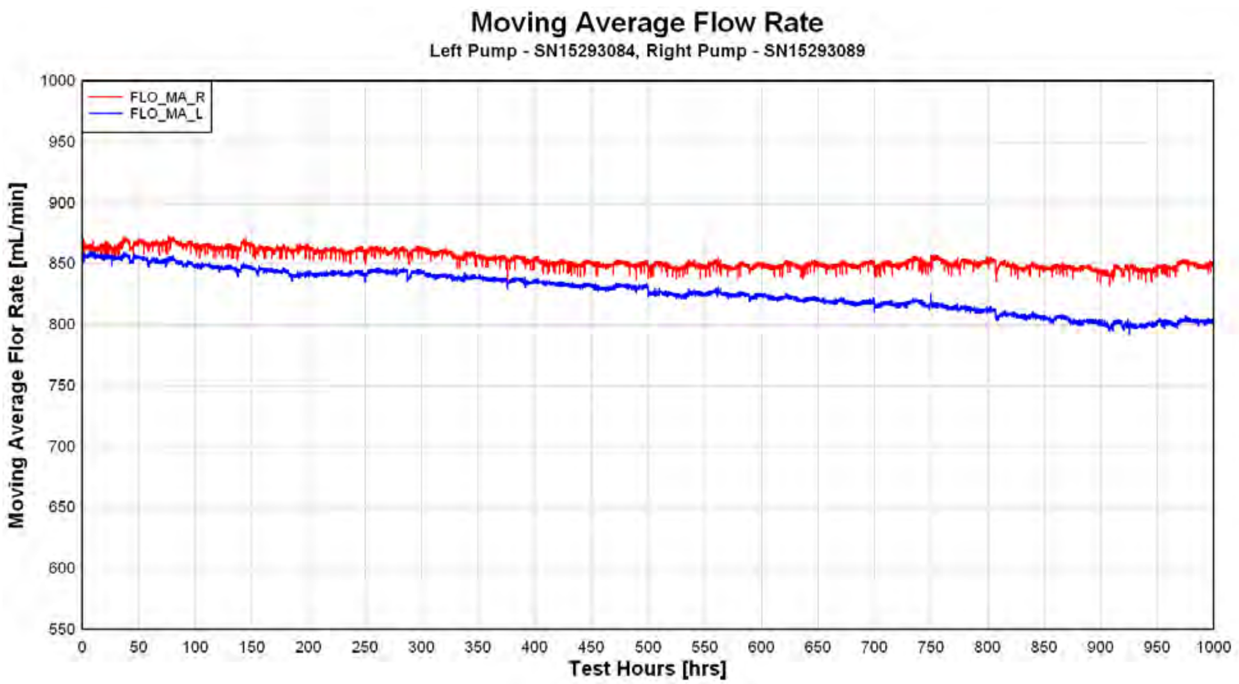


Figure A-2. Pump Flow, Moving Average

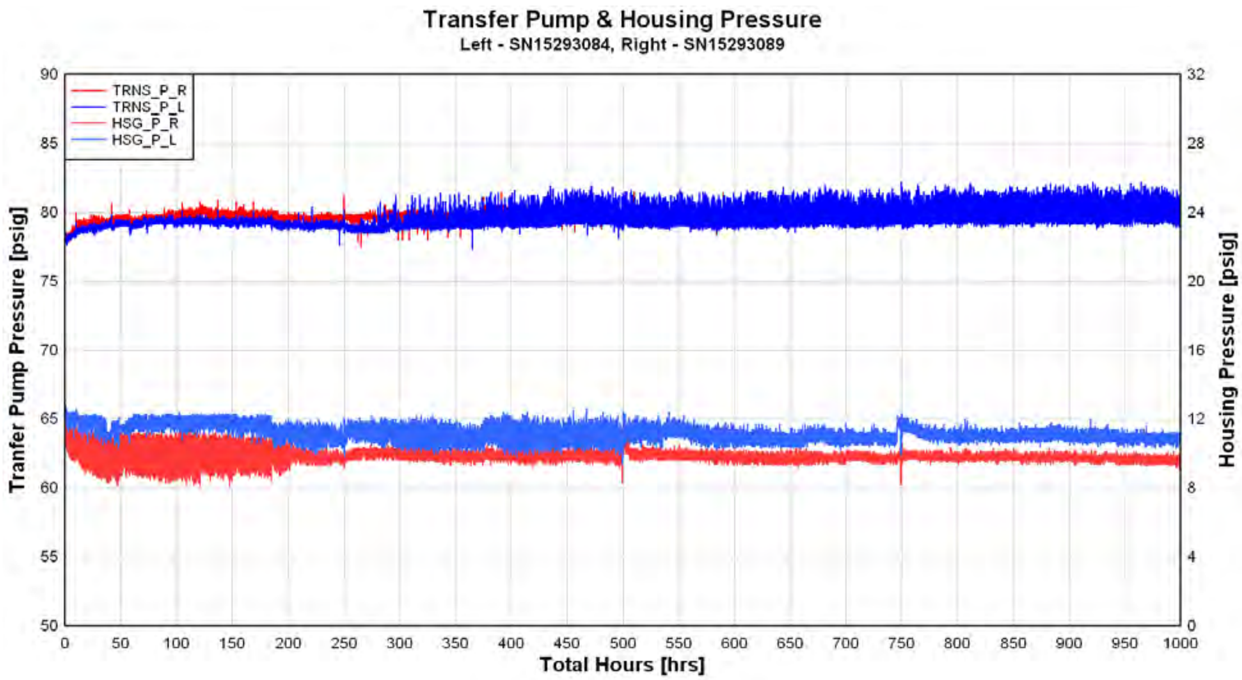


Figure A-3. Transfer Pump & Housing Pressure

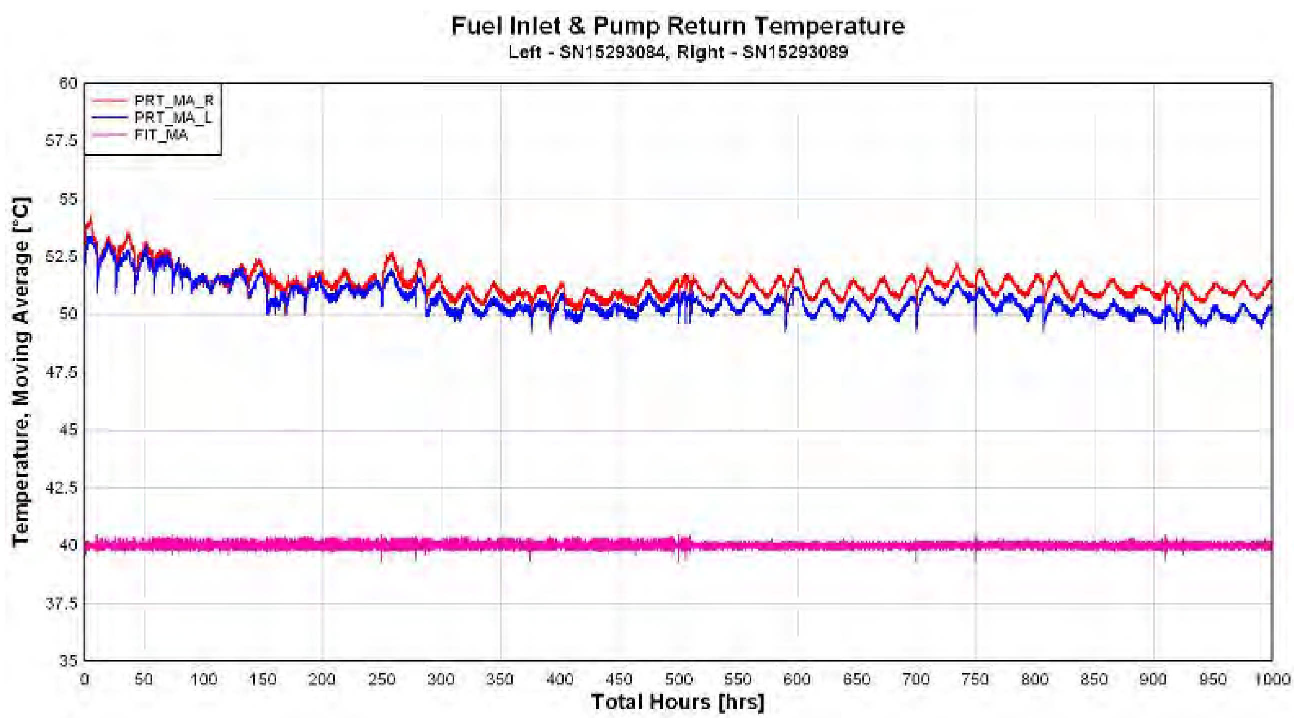


Figure A-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table A-3. (Note – Calibration data to be used as reference only)

Table A-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 1			Test Duration : 1000-hrs.		
Test Fuel :	DF-2 as purchased @ 105°F			SN : 15293084			SN : 15293089		
PUMP RPM	Description	Specification		Pump Duration : 1000-hrs.			Pump Duration : 1000-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	**63 psi**	-1 psi	62 psi	62 psi	psi
	Return Fuel	225 cc	375 cc	289 cc	320 cc	-31 cc	308 cc	300 cc	8 cc
350	Low Idle	12 cc	16 cc	15 cc	**9 cc**	6 cc	14 cc	**9 cc**	5 cc
	Housing psi.	8 psi	12 psi	9.0 psi	9.0 psi	.0 psi	**7.5 psi**	8.0 psi	-.5 psi
	Advance	3.50°		4.30°	5.63°	-1.33°	4.00°	4.70°	-.70°
	Cold Advance Solenoid	.0 psi	1.0 psi	.5 psi	.5 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	**66.0 cc**	**63.0 cc**	3.0 cc	67.0 cc	**66.0 cc**	1.0 cc
1600	WOT Fuel delivery	60 cc		64 cc	**59 cc**	5 cc	64 cc	60 cc	4 cc
	WOT Advance	2.50°	3.50°	3.20°	3.71°	-.51°	3.43°	4.13°	-.70°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	23.0 cc	-1.0 cc
	Face Cam Advance	5.25°	7.25°	6.10°	6.11°	-.01°	6.20°	6.45°	-.25°
	Low Idle	11.0°	12.0°	**10.6°**	11.2°	-.6°	11.1°	11.1°	.0°
1825	Fuel Delivery	33 cc		38 cc	58 cc	-20 cc	38 cc	60 cc	-22 cc
1950	High Idle		15 cc	8 cc	3 cc	5 cc	3 cc	8 cc	-5 cc
	Transfer pump psi.		125 psi	103 psi	105 psi	-2 psi	101 psi	106 psi	-5 psi
200	WOT Fuel Delivery	58 cc		61 cc	**57 cc**	4 cc	60 cc	60 cc	0 cc
	WOT Shut-Off		4 cc	1 cc	1 cc	-1 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		53 cc	48 cc	5 cc	48 cc	48 cc	cc
	Transfer pump psi.	16 psi		26 psi	29 psi	-3 psi	25 psi	27 psi	-2 psi
	Housing psi.	.0 psi	12 psi	7.0 psi	7 psi	0 psi	5 psi	6 psi	-1 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table A-4 and Table A-5.

Table A-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15293084	Test Number: 1	
Fuel Description : DF-2 as purchased @ 105°F				
	Date:	5/25/2010	10/22/2010	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2515	3.2597	0.0082
Measurement 2		3.2516	3.2597	0.0081
Measurement 3		3.2515	3.2598	0.0083
Measurement 4		3.2515	3.2597	0.0082
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2275	3.2397	0.0122
Measurement 2		3.2275	3.2397	0.0122
Measurement 3		3.2274	3.2396	0.0122
Measurement 4		3.2274	3.2396	0.0122
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2192	3.2257	0.0065
Measurement 2		3.2191	3.2257	0.0066
Measurement 3		3.2191	3.2256	0.0065
Measurement 4		3.2191	3.2257	0.0066
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2645	3.2710	0.0065
Measurement 2		3.2645	3.2710	0.0065
Measurement 3		3.2644	3.2708	0.0064
Measurement 4		3.2645	3.2709	0.0064
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2515	3.2597	0.0082
Transfer Pump Blade 2		3.2275	3.2397	0.0122
Transfer Pump Blade 3		3.2191	3.2257	0.0065
Transfer Pump Blade 4		3.2645	3.2709	0.0065
	Roller to Roller (in)	1.9762	1.9725	-0.0037
	Eccentricity (in.)	0.0040	0.0040	0.0000
	Drive Backlash (In)	0.0030	0.0050	0.0020

Table A-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15293089	Test Number: 1	
Fuel Description : DF-2 as purchased @ 105°F				
	Date:	5/25/2010	10/22/2010	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2398	3.2484	0.0086
Measurement 2		3.2398	3.2483	0.0085
Measurement 3		3.2399	3.2483	0.0084
Measurement 4		3.2397	3.2483	0.0086
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2318	3.2419	0.0101
Measurement 2		3.2318	3.2419	0.0101
Measurement 3		3.2317	3.2420	0.0103
Measurement 4		3.2317	3.2421	0.0104
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2467	3.2516	0.0049
Measurement 2		3.2466	3.2518	0.0052
Measurement 3		3.2466	3.2516	0.0050
Measurement 4		3.2466	3.2516	0.0050
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2537	3.2606	0.0069
Measurement 2		3.2538	3.2605	0.0067
Measurement 3		3.2538	3.2604	0.0066
Measurement 4		3.2538	3.2604	0.0066
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2398	3.2483	0.0085
Transfer Pump Blade 2		3.2318	3.2420	0.0102
Transfer Pump Blade 3		3.2466	3.2517	0.0050
Transfer Pump Blade 4		3.2538	3.2605	0.0067
	Roller to Roller (in)	1.9760	1.9750	-0.0010
	Eccentricity (in.)	0.0040	0.0040	0.0000
	Drive Backlash (In)	0.0035	0.0050	0.0015

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table A-6.

Table A-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation

6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
1	15293084	DF-2 as purchased @ 105°F	1-1	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			1-2	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			1-3	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			1-4	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			1-5	2175	1950	Pass	Pass	Pass	Pass	Pass	Pass
			1-6	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			1-7	2150	1750	Pass	Pass	Pass	Pass	Pass	Pass
			1-8	2100	1725	Pass	Pass	Pass	Pass	Pass	Pass
1	15293089	DF-2 as purchased @ 105°F	1-11	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			1-12	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			1-13	2100	1825	Pass	Pass	Pass	Pass	Pass	Pass
			1-14	2200	1925	Pass	Pass	Pass	Pass	Pass	Pass
			1-15	2100	1775	Pass	Pass	Pass	Pass	Pass	Pass
			1-16	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			1-17	2100	1775	Pass	Fail	Pass	Pass	Pass	Pass
			1-18	2175	1775	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 15 out of 16								

Comments :

DF2 as purchased @105°F

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table A-7 and Table A-8.

Table A-7. Stanadyne Left Pump Parts Evaluation

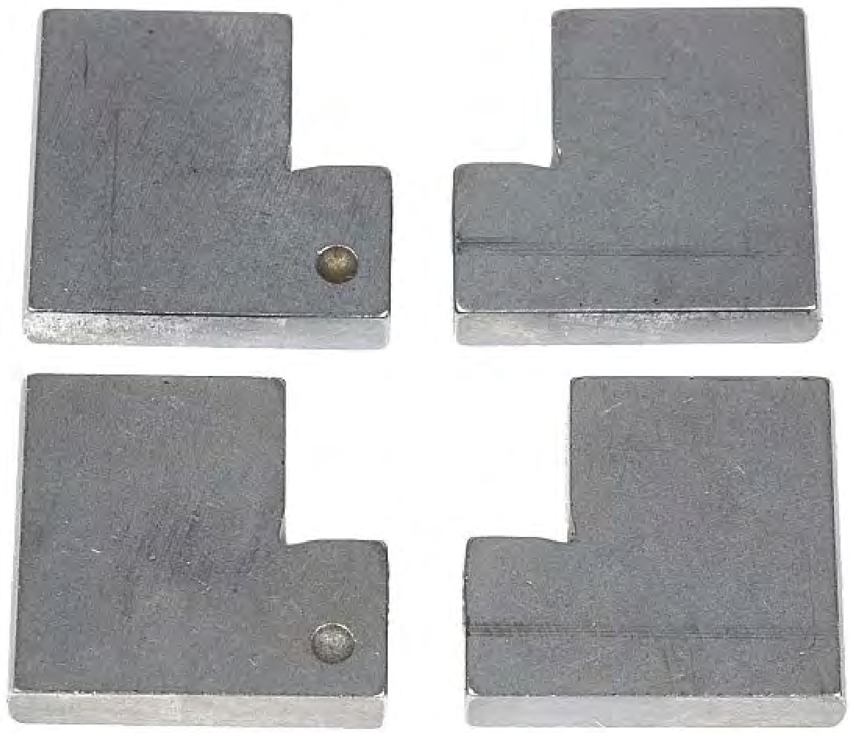
Pump Type : DB2831-5079 (arctic)		SN: 15293084
Test Condition : DF-2 as purchased @ 105°F		Pump Duration : 1000-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Light polishing wear at rotor slots and liner contact	1
BLADE SPRINGS	Normal	1
LINER	Polishing wear	1
TRANSFER PUMP REGULATOR	Light wear mark from rotor contact	1
REGULATOR PISTON	Light polishing wear in two spots	1
ROTOR	Normal	0.5
ROTOR RETAINERS	Light wear from rotor contact	1
DELIVERY VALVE	Light polishing wear. Valve spring broken	1
PLUNGERS	Very light polished spots in some areas	0.5
SHOES	Dimple on back of one shoe. Normal wear at roller contact.	1
ROLLERS	Light scarring	1.5
LEAF SPRING	Light wear at shoe contact	1
CAM RING	Normal	1
THRUST WASHER	Light polishing at weight contact	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear at foot from weight contact	1
LINK HOOK	Normal	1
METERING VAVLE	Very light polishing wear	0.5
DRIVE SHAFT TANG	Light polishing marks	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scuffing wear at top right side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.043

Table A-8. Stanadyne Right Pump Parts Evaluation

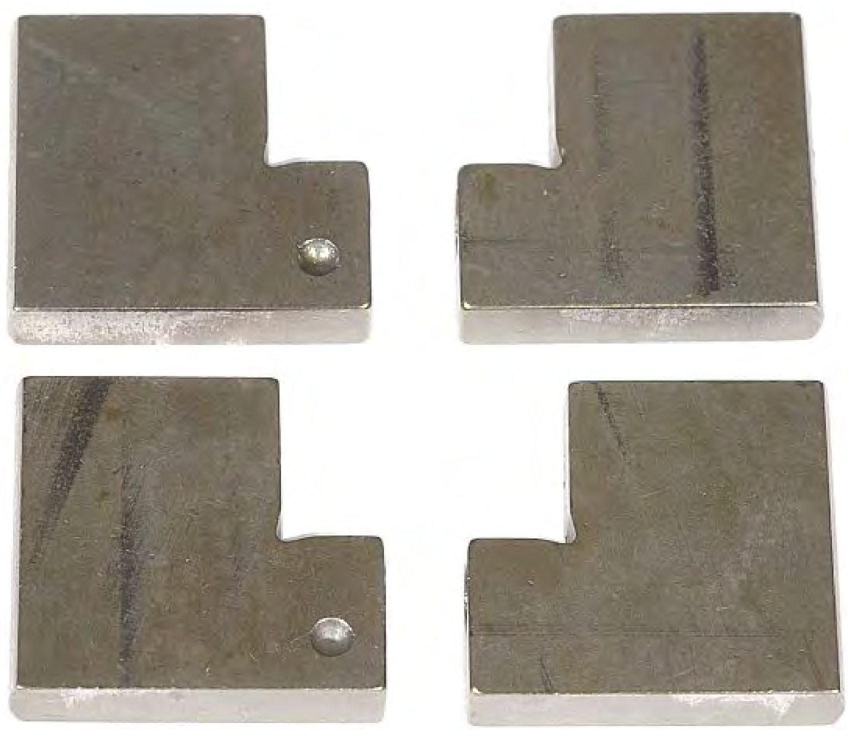
Pump Type : DB2831-5079 (arctic)	SN: 15293089
Test Condition : DF-2 as purchased @ 105°F	Pump Duration : 1000-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Light polishing wear at rotor slots and liner contact	1
BLADE SPRINGS	Normal	1
LINER	Polishing wear	1
TRANSFER PUMP REGULATOR	Light wear mark from rotor contact	1
REGULATOR PISTON	Light polishing wear in two spots	1
ROTOR	Normal	0.5
ROTOR RETAINERS	Light wear from rotor contact	1
DELIVERY VALVE	Light polishing wear. Valve spring broken	1
PLUNGERS	Very light polished spots in some areas	0.5
SHOES	Light scratches on right shoe. Normal wear at roller contact.	1.5
ROLLERS	Light scarring	1.5
LEAF SPRING	Light wear at shoe contact	1
CAM RING	Normal	1
THRUST WASHER	Groove worn into washer surface at weight contact	2.5
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Worn at foot from thrust washer contact	2
LINK HOOK	Normal	1
METERING VAVLE	Very light polishing wear	0.5
DRIVE SHAFT TANG	Light polishing marks	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scuffing wear at top right side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.174

PHOTOGRAPHS FOR LEFT PUMP



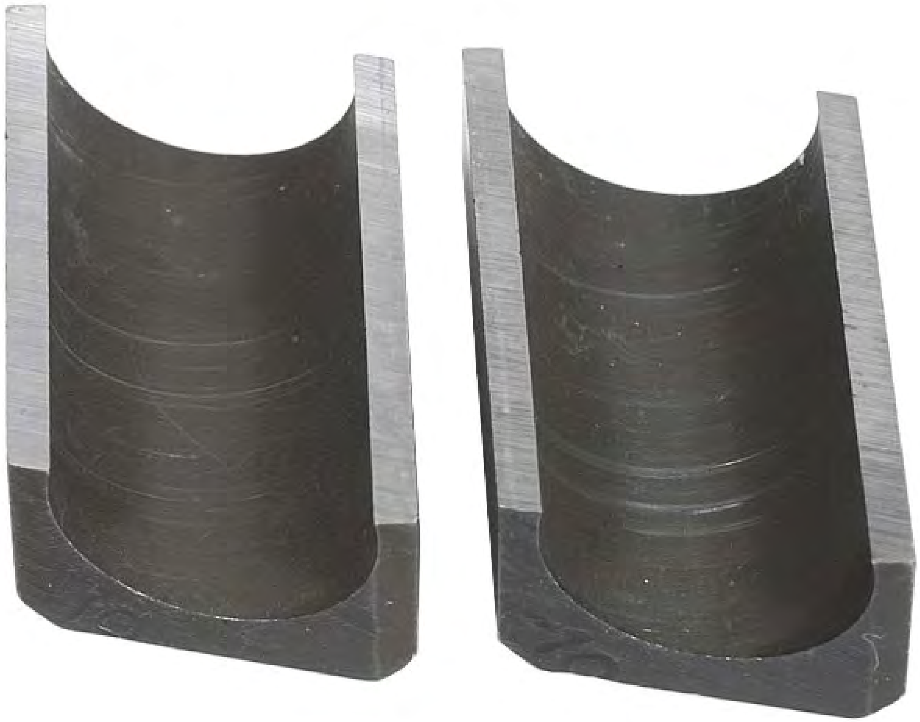
SN15293084 Transfer Pump Blades (Side), Before



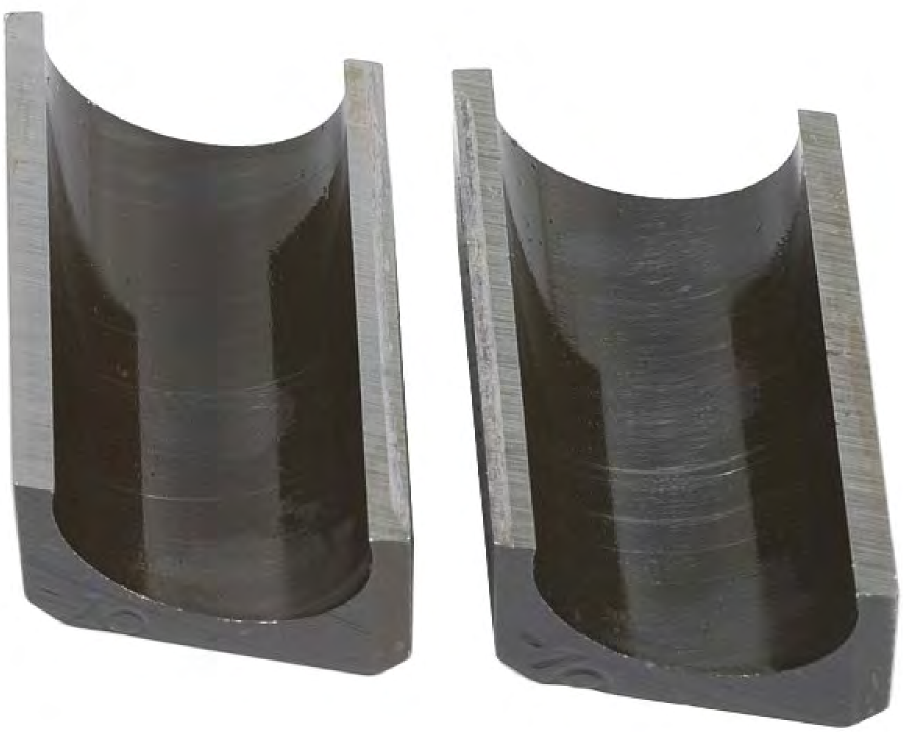
SN15293084 Transfer Pump Blades (Side), After

SN15293084 Transfer Pump Blades (Profile), Before

SN15293084 Transfer Pump Blades (Profile), After

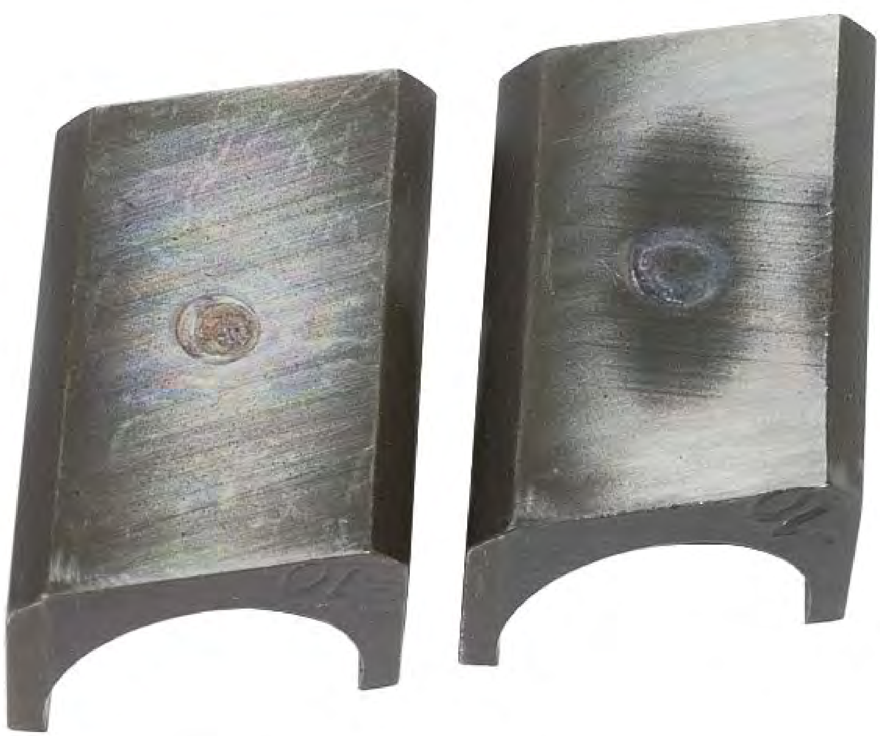


SN15293084 Shoes (Front), Before



SN15293084 Shoes (Front), After

SN15293084 Shoes (Back), Before



SN15293084 Shoes (Back), After

SN15293084 Rollers, Before

SN15293084 Rollers, After

SN15293084 Piston Plungers, Before

SN15293084 Piston Plungers, After

SN15293084 Thrust Washer, Before

SN15293084 Thrust Washer, After

SN15293084 Governor Weight, Before

SN15293084 Governor Weight, After

SN15293084 Cam Ring, Before

SN15293084 Cam Ring, After

SN15293084 Eccentric Ring, Before

SN15293084 Eccentric Ring, After

SN15293084 Rotor (Front), Before

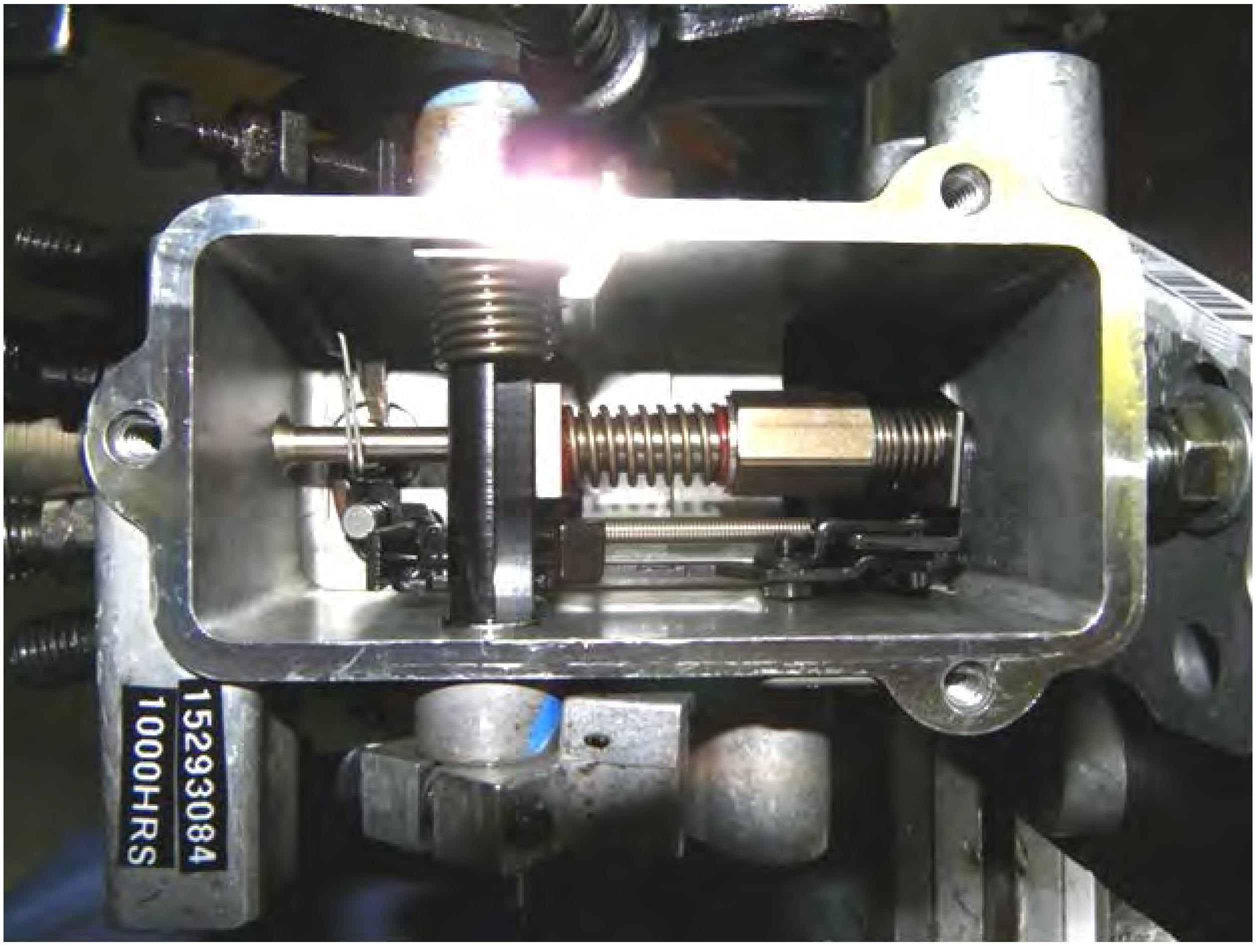
SN15293084 Rotor (Front), After

SN15293084 Rotor (Back), Before

SN15293084 Rotor (Back), After

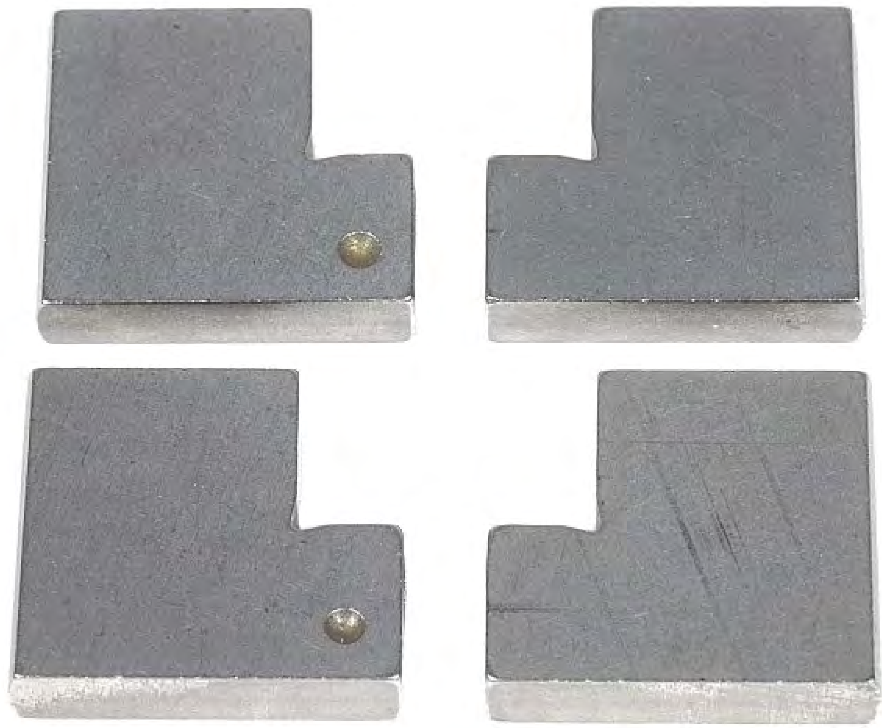
SN15293084 Drive Tang, Before

SN15293084 Drive Tang, After

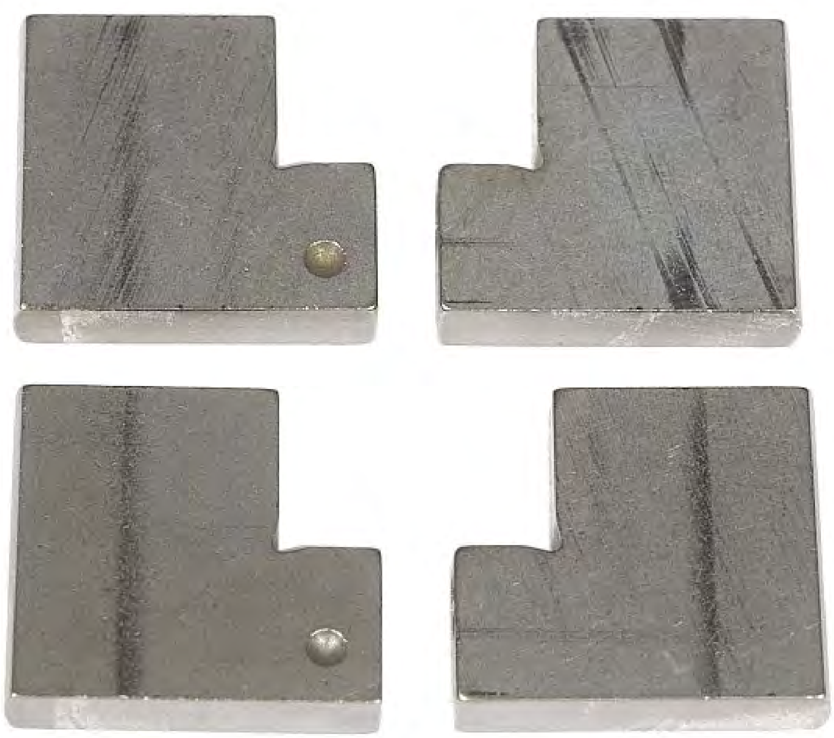


SN15293084 Governor Assembly After

PHOTOGRAPHS FOR RIGHT PUMP



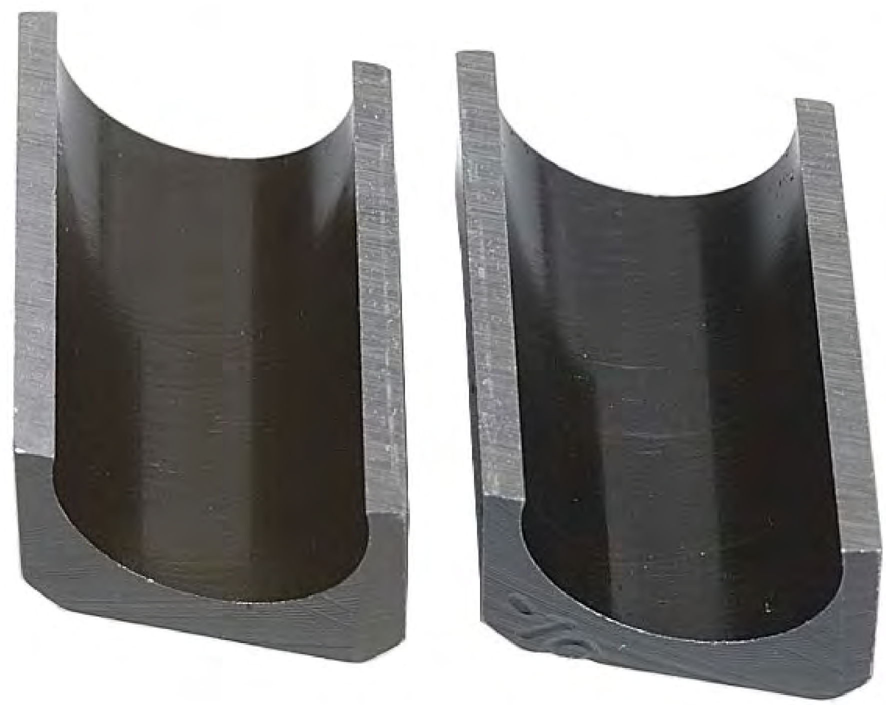
SN15293089 Transfer Pump Blades, Before



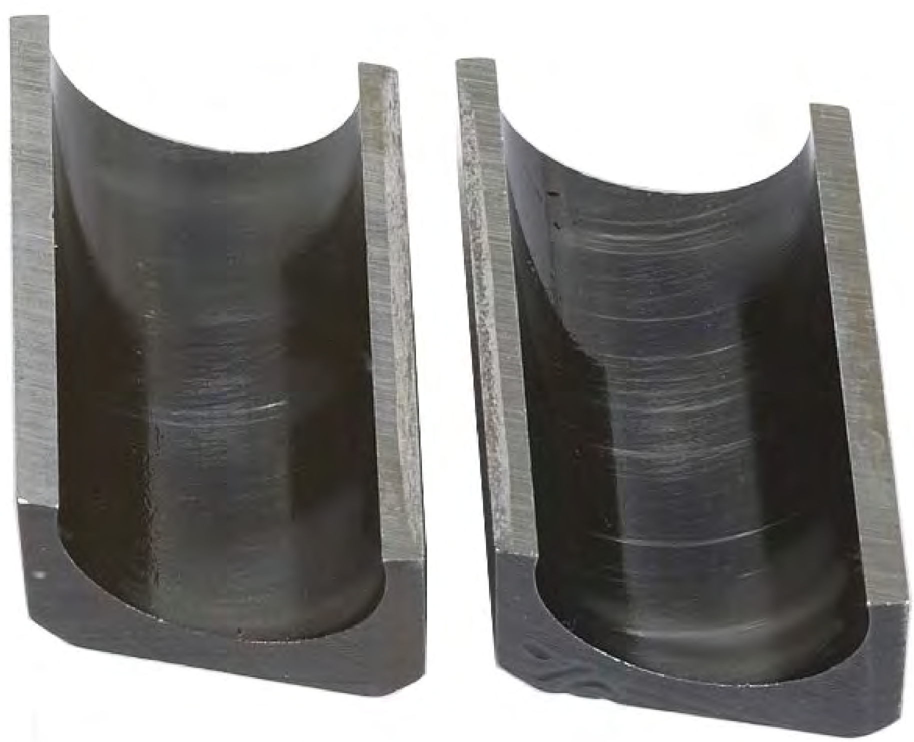
SN15293089 Transfer Pump Blades, Before

SN15293089 Transfer Pump Blades (Profile), Before

SN15293089 Transfer Pump Blades (Profile), After



SN15293089 Shoes (Front), Before



SN15293089 Shoes (Front), After

SN15293089 Shoes (Back), Before

SN15293089 Shoes (Back), After

SN15293089 Rollers, Before

SN15293089 Rollers, After

SN15293089 Piston Plungers, Before

SN15293089 Piston Plungers, After

SN15293089 Thrust Washer, Before

SN15293089 Thrust Washer, After

SN15293089 Governor Weight, Before

SN15293089 Governor Weight, After

SN15293089 Cam Ring, Before

SN15293089 Cam Ring, After

SN15293089 Eccentric Ring, Before

SN15293089 Eccentric Ring, After

SN15293089 Rotor (Front), Before

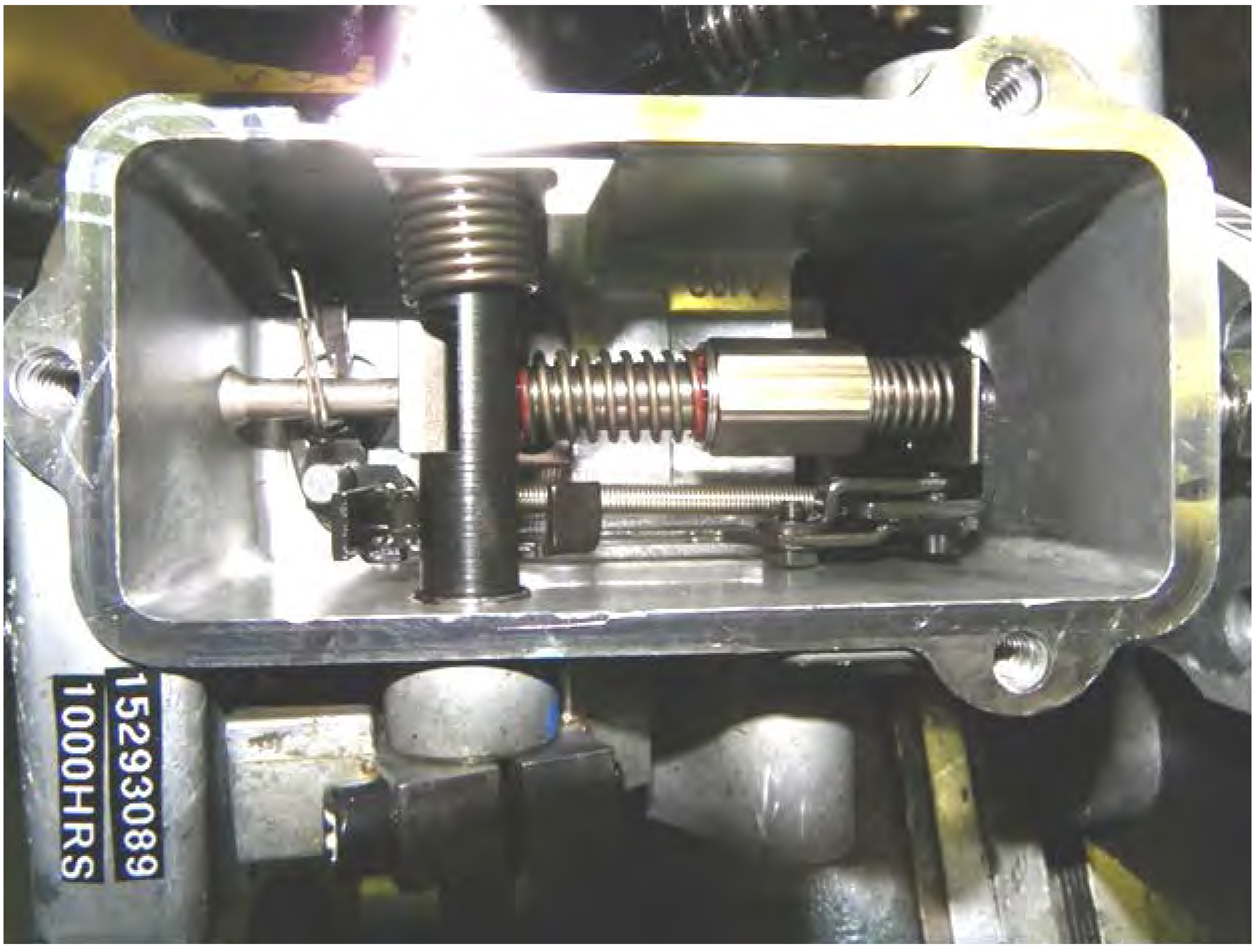
SN15293089 Rotor (Front), After

SN15293089 Rotor (Back), Before

SN15293089 Rotor (Back), After

SN15293089 Drive Tang, Before

SN15293089 Drive Tang, After



SN15293089 Governor Assembly, After

APPENDIX B

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Certification 2007 Diesel
Test Number: C4T2-57-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Certification 2007 Diesel
Test Fuel ID: AF 7469
Test Temperature: 57°C (135°F)
Test Number: C4T2-57-1000
Start of Test Date: September 7, 2010
End of Test Date: November 10, 2010
Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure B-1.

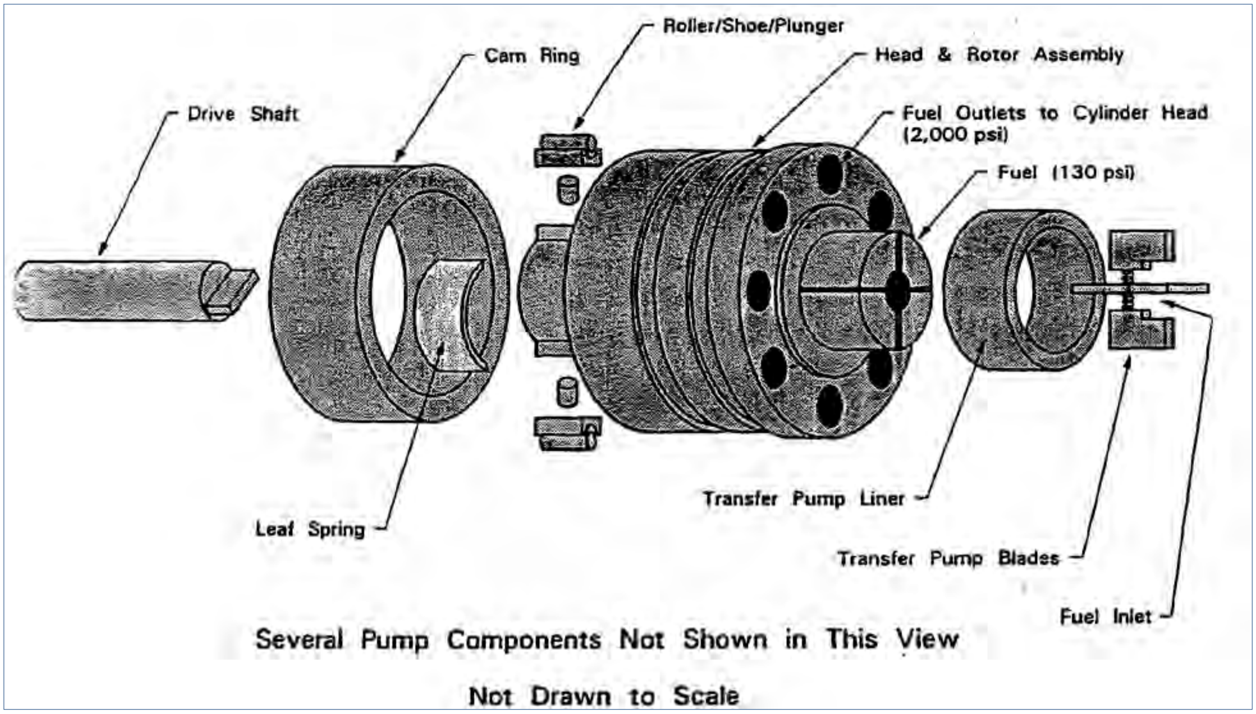


Figure B-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table B-1.

Table B-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	57 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table B-2.

Table B-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	2.43
FLO_R	Injected Flow-rate [mL/min]	838.85	9.67
FUELIN_P	Fuel Inlet Pressure [psig]	2.8	0.16
TRNS_P_R	Transfer Pump Pressure [psig]	77.65	0.43
HSG_P_R	Pump Housing Pressure [psig]	11.15	0.51
RTRN_T_R	Fuel Return Temperature [°C]	65.51	2.65
FUEL_T	Fuel Tank Temperature [°C]	27.8	3.24
FUELIN_T	Fuel Inlet Temperature [°C]	57.0	0.35

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure B-2 through Figure B-4.

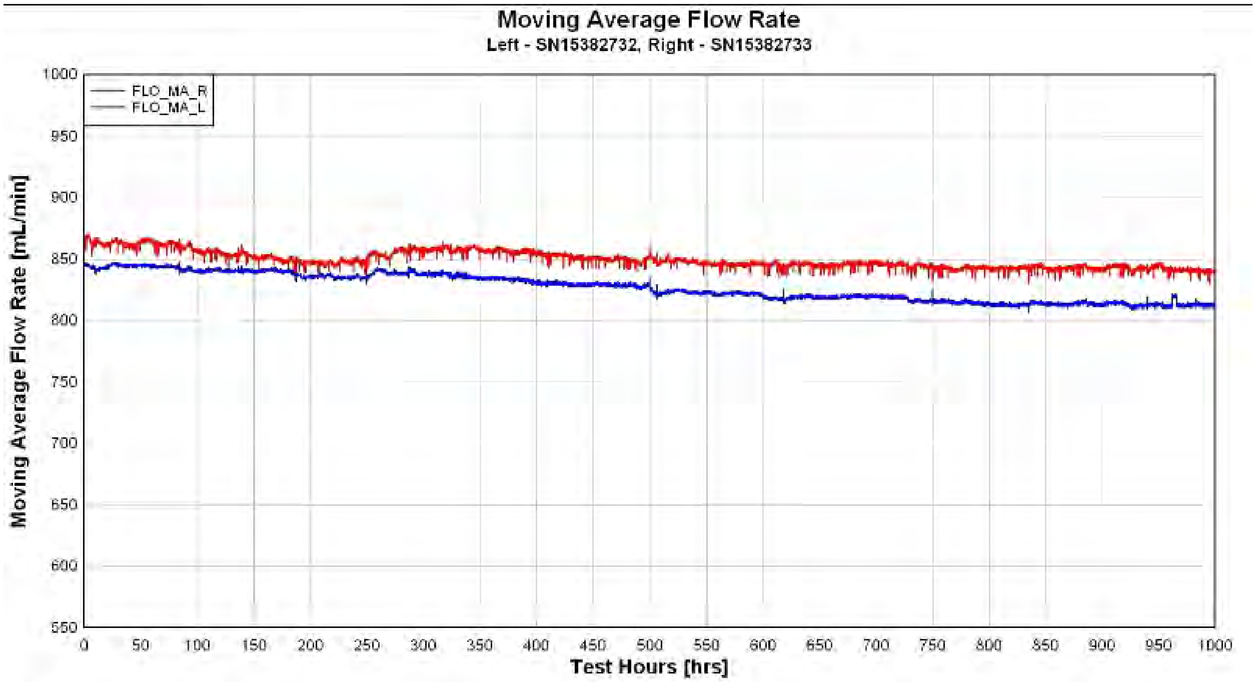


Figure B-2. Pump Flow, Moving Average

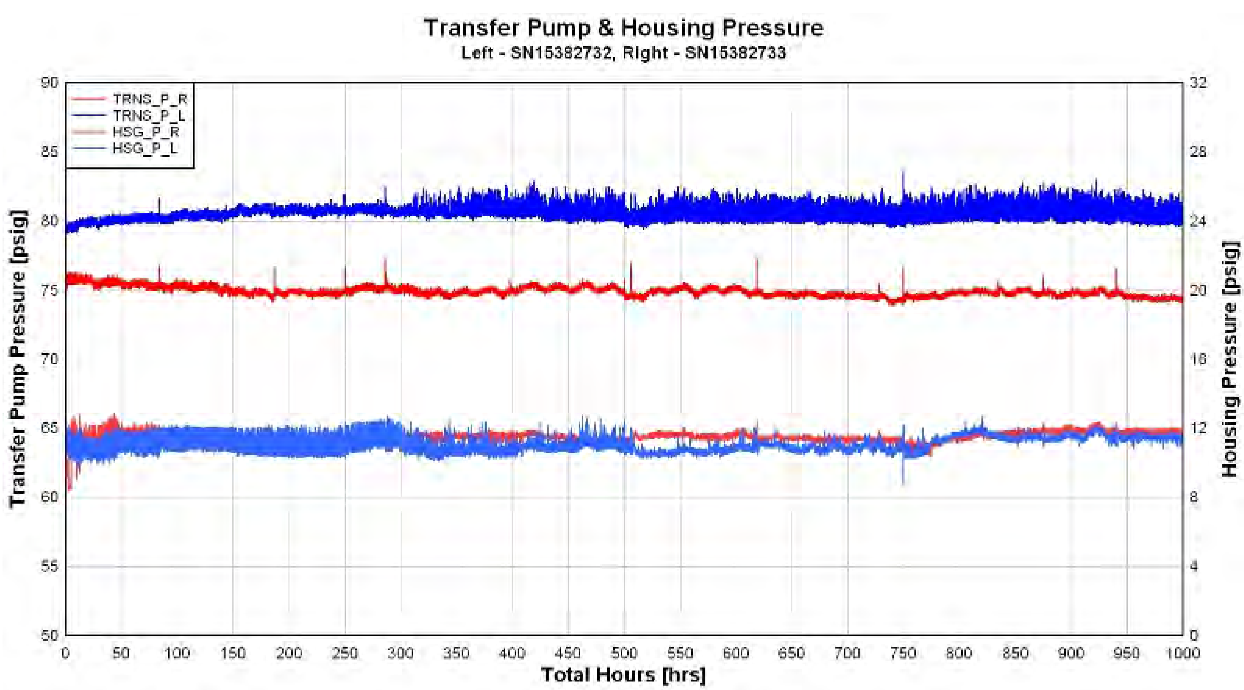


Figure B-3. Transfer Pump & Housing Pressure

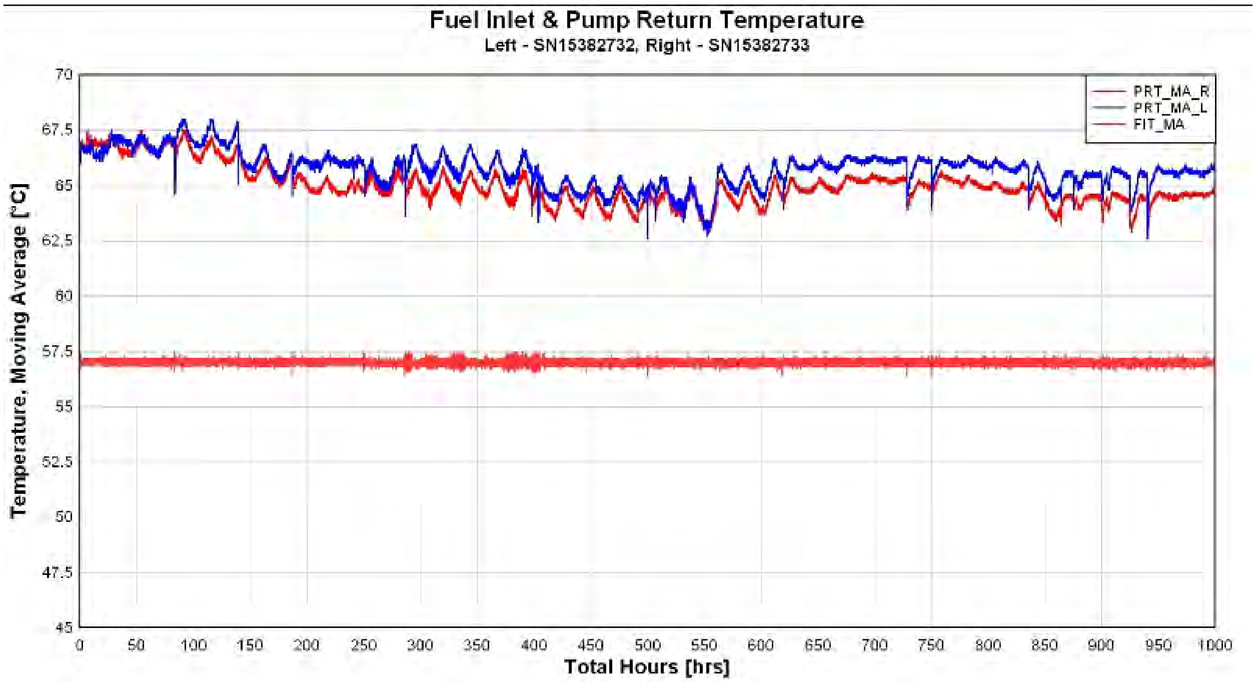


Figure B-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table B-3. (Note – Calibration data to be used as reference only)

Table B-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 2			Test Duration : 1000-hrs.		
Test Fuel :	DF-2 as purchased @ 135°F			SN : 15382732			SN : 15382733		
PUMP RPM	Description	Specification		Pump Duration : 1000-hrs.			Pump Duration : 1000-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	**64 psi**	-2 psi	62 psi	62 psi	psi
	Return Fuel	225 cc	375 cc	270 cc	350 cc	-80 cc	256 cc	340 cc	-84 cc
350	Low Idle	12 cc	16 cc	12 cc	**0 cc**	12 cc	15 cc	12 cc	3 cc
	Housing psi.	8 psi	12 psi	9.0 psi	**3.0 psi**	6.0 psi	11.0 psi	10.0 psi	1.0 psi
	Advance	3.50°		4.91°	5.60°	-.69°	3.82°	**2.26°**	1.56°
	Cold Advance Solenoid	.0 psi	1.0 psi	1.0 psi	.0 psi	1.0 psi	1.0 psi	.5 psi	.5 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	69.0 cc	**65.0 cc**	4.0 cc	69.0 cc	**65.0 cc**	4.0 cc
1600	WOT Fuel delivery	60 cc		67 cc	63 cc	4 cc	66 cc	63 cc	3 cc
	WOT Advance	2.50°	3.50°	3.22°	2.80°	.42°	2.85°	1.93°	.92°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	22.0 cc	.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	5.70°	6.53°	-.83°	6.20°	5.81°	.39°
	Low Idle	11.0°	12.0°	11.2°	11.2°	.0°	11.1°	11.2°	-.1°
1825	Fuel Delivery	33 cc		39 cc	59 cc	-20 cc	39 cc	60 cc	-21 cc
1950	High Idle		15 cc	2 cc	1 cc	1 cc	2 cc	2 cc	0 cc
	Transfer pump psi.		125 psi	106 psi	110 psi	-4 psi	102 psi	102 psi	0 psi
200	WOT Fuel Delivery	58 cc		62 cc	60 cc	2 cc	65 cc	61 cc	4 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		53 cc	48 cc	5 cc	54 cc	50 cc	4 cc
	Transfer pump psi.	16 psi		30 psi	30 psi	0 psi	31 psi	27 psi	4 psi
	Housing psi.	.0 psi	12 psi	6.0 psi	9 psi	-3 psi	8 psi	7 psi	1 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table B-4 and Table B-5.

Table B-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15382732	Test Number: 2	
Fuel Description : DF-2 as purchased @ 135°F				
	Date:	7/15/2010	12/7/2010	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2760	3.2807	0.0047
Measurement 2		3.2763	3.2808	0.0045
Measurement 3		3.2763	3.2807	0.0044
Measurement 4		3.2761	3.2806	0.0045
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2511	3.2514	0.0003
Measurement 2		3.2512	3.2515	0.0003
Measurement 3		3.2513	3.2515	0.0002
Measurement 4		3.2512	3.2514	0.0002
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2688	3.2688	0.0000
Measurement 2		3.2689	3.2687	-0.0002
Measurement 3		3.2689	3.2687	-0.0002
Measurement 4		3.2689	3.2687	-0.0002
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2921	3.2916	-0.0005
Measurement 2		3.2920	3.2915	-0.0005
Measurement 3		3.2921	3.2915	-0.0006
Measurement 4		3.2920	3.2915	-0.0005
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2762	3.2807	0.0045
Transfer Pump Blade 2		3.2512	3.2515	0.0003
Transfer Pump Blade 3		3.2689	3.2687	-0.0002
Transfer Pump Blade 4		3.2921	3.2915	-0.0005
	Roller to Roller (in)	1.9765	1.9760	-0.0005
	Eccentricity (in.)	0.0070	0.0060	-0.0010
	Drive Backlash (In)	0.0045	0.0050	0.0005

Table B-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15382733	Test Number: 2	
Fuel Description : DF-2 as purchased @ 135°F				
	Date:	7/15/2010	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.3014	3.3004	-0.0010
Measurement 2		3.3013	3.3004	-0.0009
Measurement 3		3.3012	3.3005	-0.0007
Measurement 4		3.3012	3.3005	-0.0007
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2472	3.2467	-0.0005
Measurement 2		3.2471	3.2468	-0.0003
Measurement 3		3.2471	3.2466	-0.0005
Measurement 4		3.2472	3.2467	-0.0005
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2648	3.2645	-0.0003
Measurement 2		3.2645	3.2645	0.0000
Measurement 3		3.2646	3.2644	-0.0002
Measurement 4		3.2648	3.2644	-0.0004
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2938	3.2968	0.0030
Measurement 2		3.2938	3.2969	0.0031
Measurement 3		3.2938	3.2968	0.0030
Measurement 4		3.2939	3.2969	0.0030
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.3013	3.3005	-0.0008
Transfer Pump Blade 2		3.2472	3.2467	-0.0004
Transfer Pump Blade 3		3.2647	3.2645	-0.0002
Transfer Pump Blade 4		3.2938	3.2969	0.0030
	Roller to Roller (in)	1.9765	1.9768	0.0003
	Eccentricity (in.)	0.0060	0.0050	-0.0010
	Drive Backlash (In)	0.0040	0.0040	0.0000

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table B-6.

Table B-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation

6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
2	15382732	DF-2 as purchased @ 135°F	2-1	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			2-2	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			2-3	2175	1925	Pass	Pass	Pass	Pass	Pass	Pass
			2-4	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			2-5	2150	1850	Pass	Pass	Pass	Pass	Pass	Pass
			2-6	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			2-7	2200	1925	Pass	Pass	Pass	Pass	Pass	Pass
			2-8	2200	1950	Pass	Pass	Pass	Pass	Pass	Pass
2	15382733	DF-2 as purchased @ 135°F	2-11	2150	1900	Pass	Pass	Pass	Pass	Pass	Pass
			2-12	2100	1900	Pass	Pass	Pass	Pass	Pass	Pass
			2-13	2200	1925	Pass	Pass	Pass	Pass	Pass	Pass
			2-14	2175	1875	Pass	Fail	Pass	Pass	Pass	Pass
			2-15	2175	1975	Pass	Pass	Pass	Pass	Pass	Pass
			2-16	2150	1900	Pass	Pass	Pass	Pass	Pass	Pass
			2-17	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			2-18	2200	1875	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 15 out of 16								

Comments : 2-12 pintle is sticky

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table B-7 and Table B-8.

Table B-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079 (arctic)	SN: 15382732
Test Condition : DF-2 as purchased @ 135°F	Pump Duration : 1000-hrs.

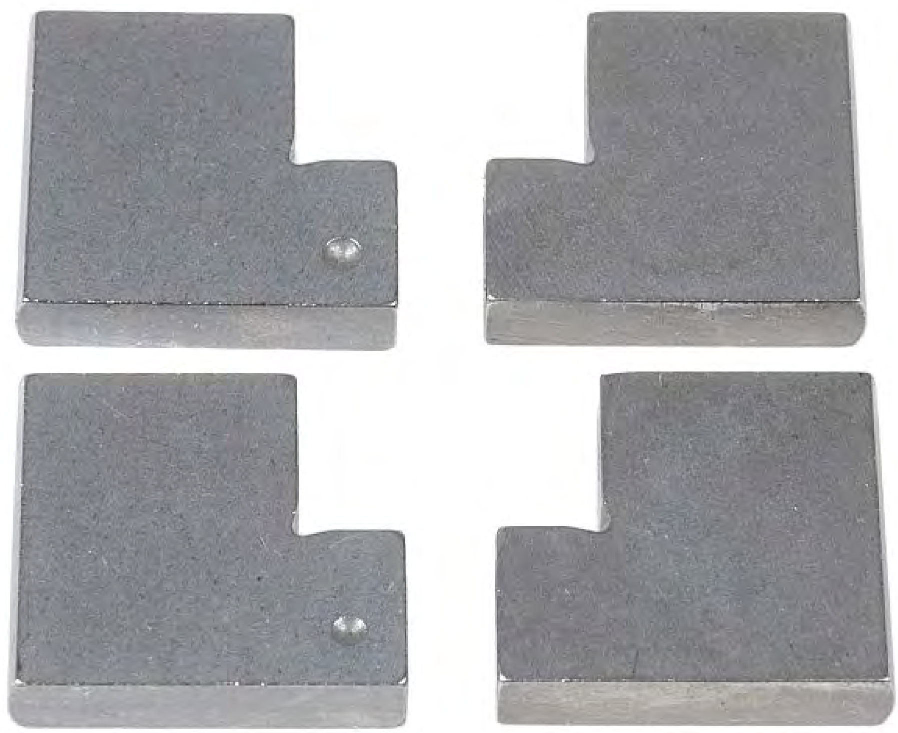
Part Name	Condition of part	Rating 0 = New 5 = Failed
BLADES	Light polishing wear at rotor slots and liner contact	1
BLADE SPRINGS	Normal	1
LINER	Polishing wear	1
TRANSFER PUMP REGULATOR	Light wear mark from rotor contact	1
REGULATOR PISTON	Light scarring wear in two spots	1.5
ROTOR	Normal	0.5
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Light polishing wear.	1
PLUNGERS	Light polished spots in some areas	1
SHOES	Dimple on back of one shoe. Light scrathing at roller contact.	1.5
ROLLERS	Darker in color scarring	1.5
LEAF SPRING	Light wear at shoe contact	1
CAM RING	Normal	1
THRUST WASHER	Light polishing at weight contact	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear at foot from weight contact	1
LINK HOOK	Normal	1
METERING VAVLE	Very light polishing wear	0.5
DRIVE SHAFT TANG	Light polishing marks	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scuffing wear at top right side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.130

Table B-8. Stanadyne Right Pump Parts Evaluation

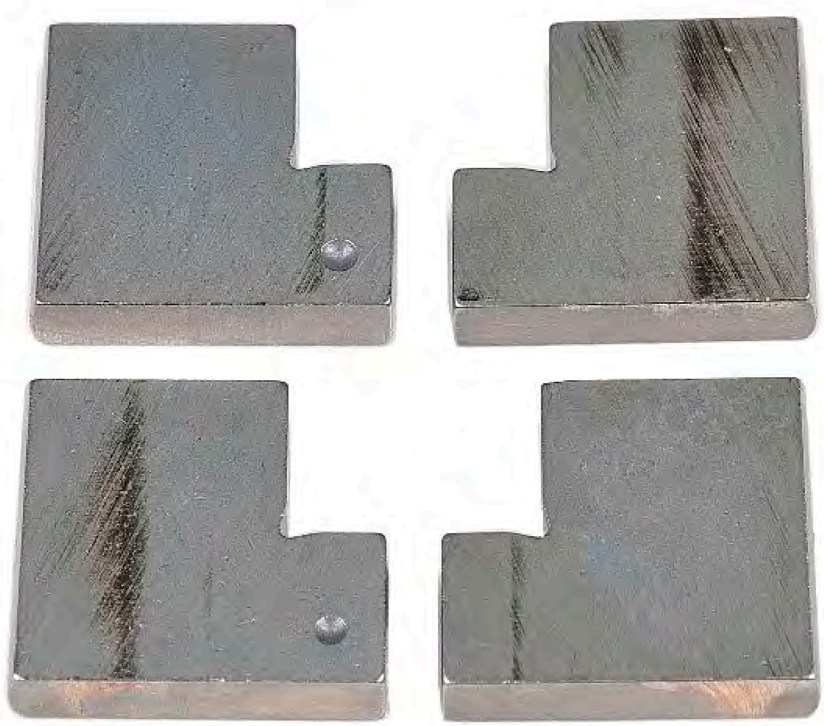
Pump Type : DB2831-5079 (arctic)	SN: 15382733
Test Condition : DF-2 as purchased @ 135°F	Pump Duration : 1000-hrs.

Part Name	Condition of part	Rating 0 = New 5 = Failed
BLADES	Light polishing wear at rotor slots and liner contact. Blade No. four worn more than the rest.	1.5
BLADE SPRINGS	Normal	1
LINER	Polishing wear	1
TRANSFER PUMP REGULATOR	Light wear mark from rotor contact	1
REGULATOR PISTON	Light polishing wear in two spots	1
ROTOR	Normal	1
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Light polishing wear.	1
PLUNGERS	Very light polished spots in some areas. Right plunger has small scuff mark.	1
SHOES	Light scrathes on right shoe. Dimple on back of left shoe.	1.5
ROLLERS	Dark in color.	1.5
LEAF SPRING	Light wear at shoe contact	1
CAM RING	Normal	1
THRUST WASHER	Light polishing at weight contact	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear at foot of thrust washer from weight contact	1
LINK HOOK	Normal	1
METERING VAVLE	Very light polishing wear	0.5
DRIVE SHAFT TANG	Light polishing marks	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scuffing wear at top right side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.152

PHOTOGRAPHS FOR LEFT PUMP



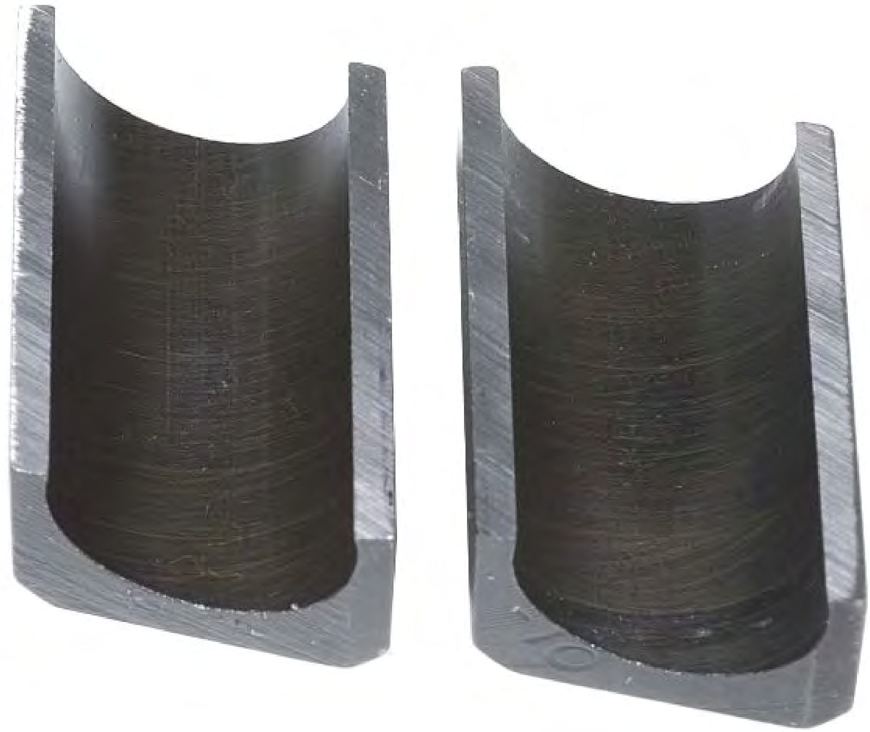
SN15382732 Transfer Pump Blades (Side), Before



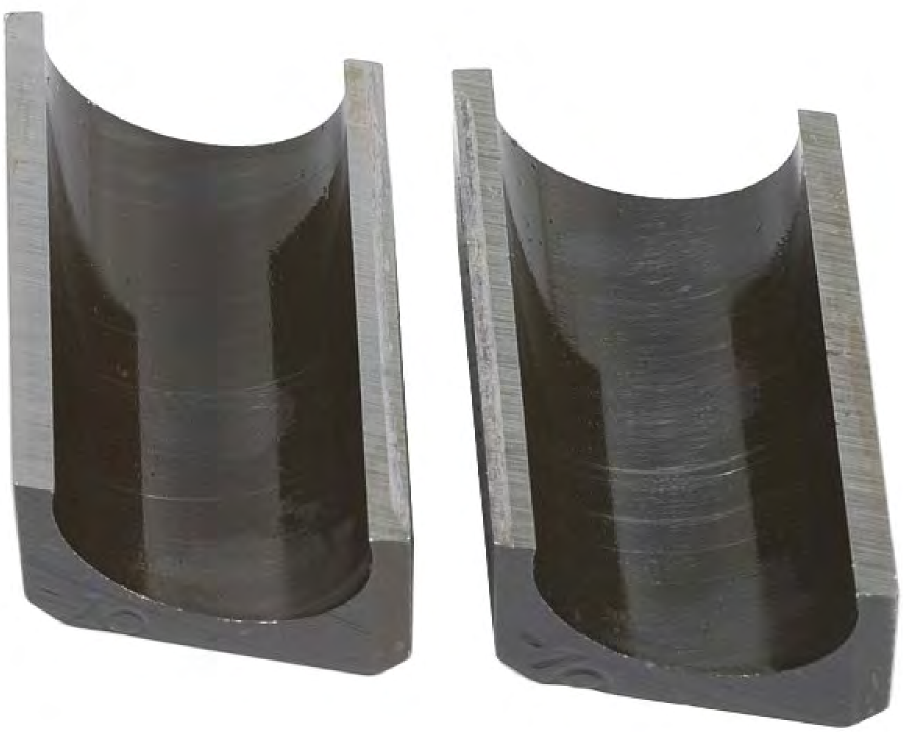
SN15382732 Transfer Pump Blades (Side), After

SN15382732 Transfer Pump Blades (Profile), Before

SN15382732 Transfer Pump Blades (Profile), After



SN15382732 Shoes (Front), Before



SN15382732 Shoes (Front), After

SN15382732 Shoes (Back), Before

SN15382732 Shoes (Back), After

SN15382732 Rollers, Before

SN15382732 Rollers, After

SN15382732 Piston Plungers, Before

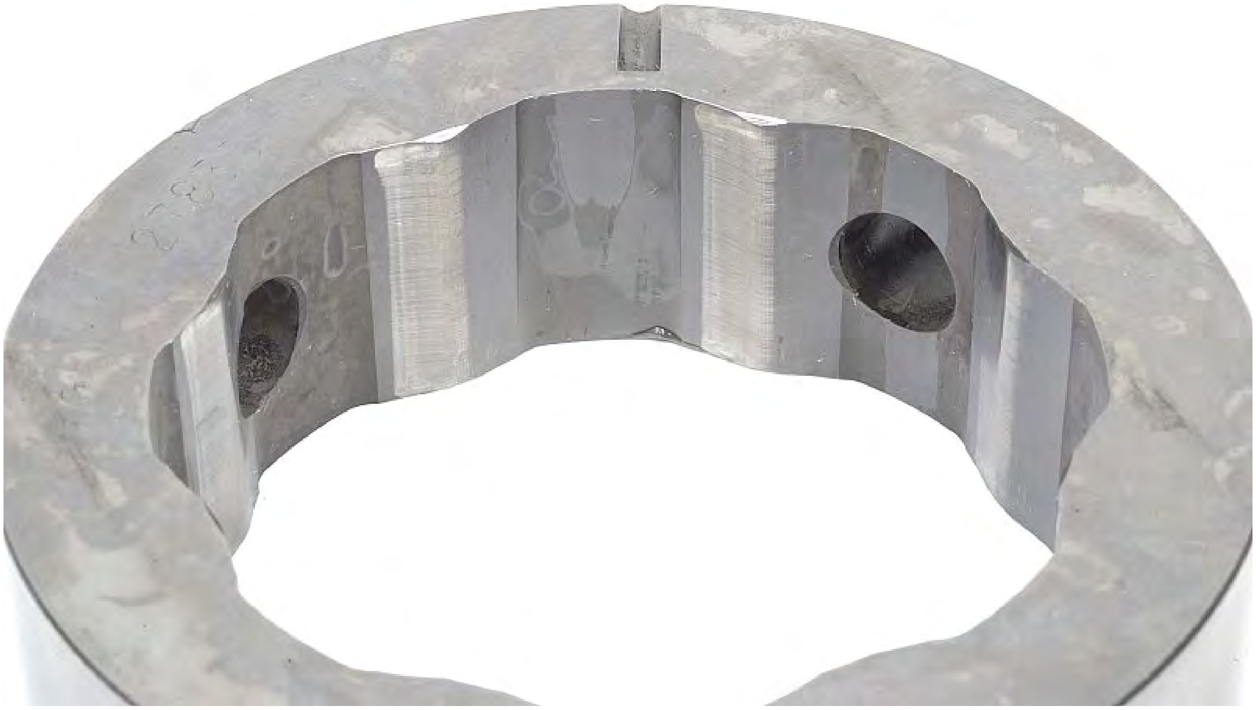
SN15382732 Piston Plungers, After

SN15382732 Thrust Washer, Before

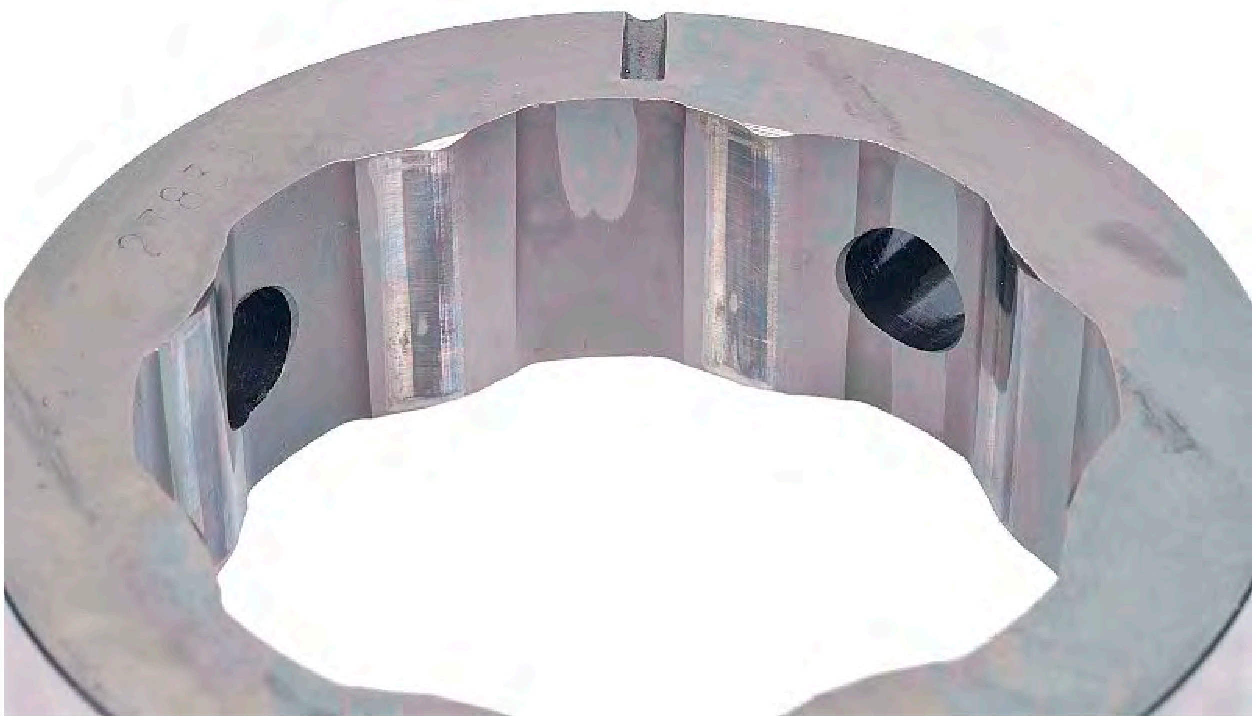
SN15382732 Thrust Washer, After

SN15382732 Governor Weight, Before

SN15382732 Governor Weight, After



SN15382732 Cam Ring, Before



SN15382732 Cam Ring, After

SN15382732 Eccentric Ring, Before

SN15382732 Eccentric Ring, After

SN15382732 Rotor (Front), Before

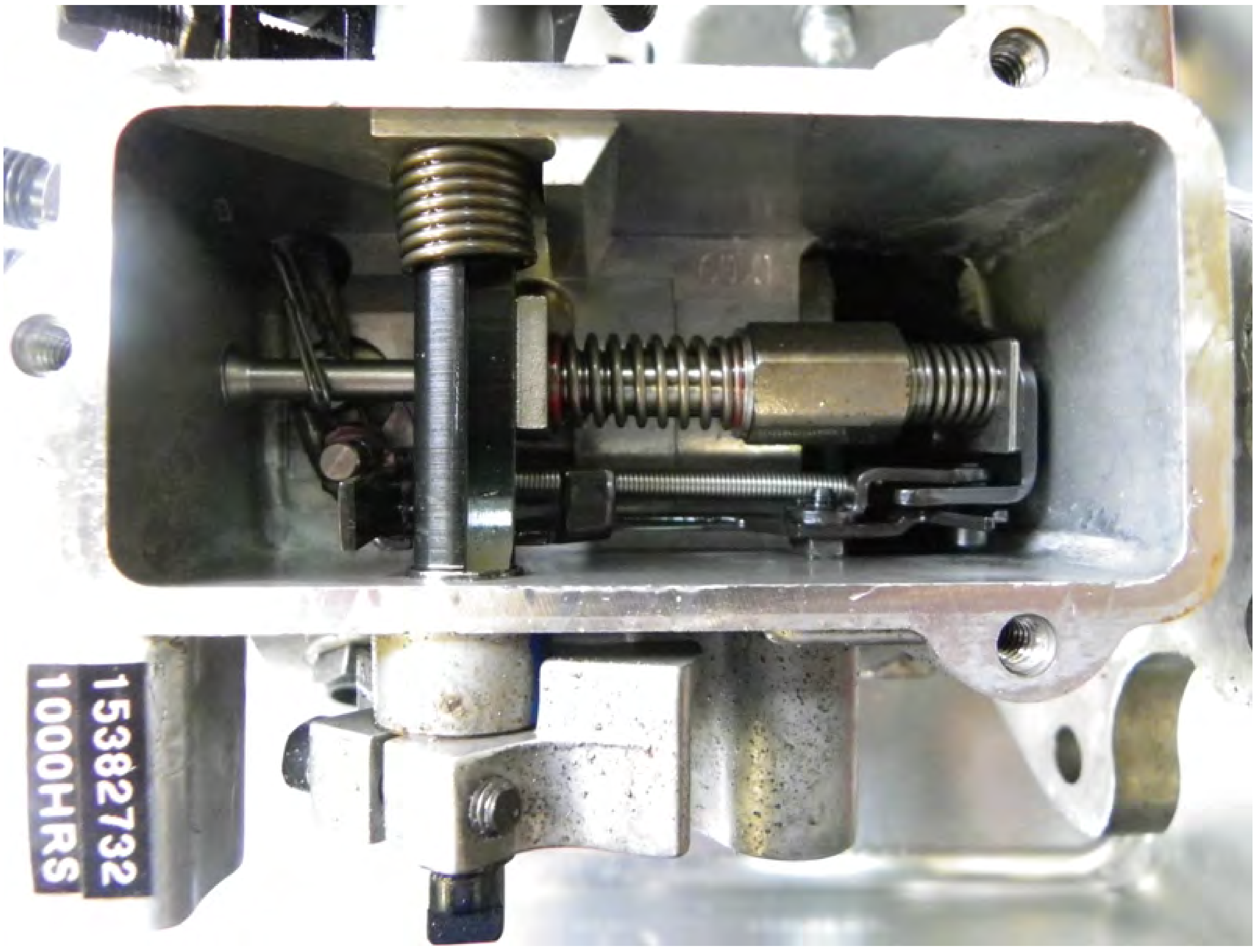
SN15382732 Rotor (Front), After

SN15382732 Rotor (Back), Before

SN15382732 Rotor (Back), After

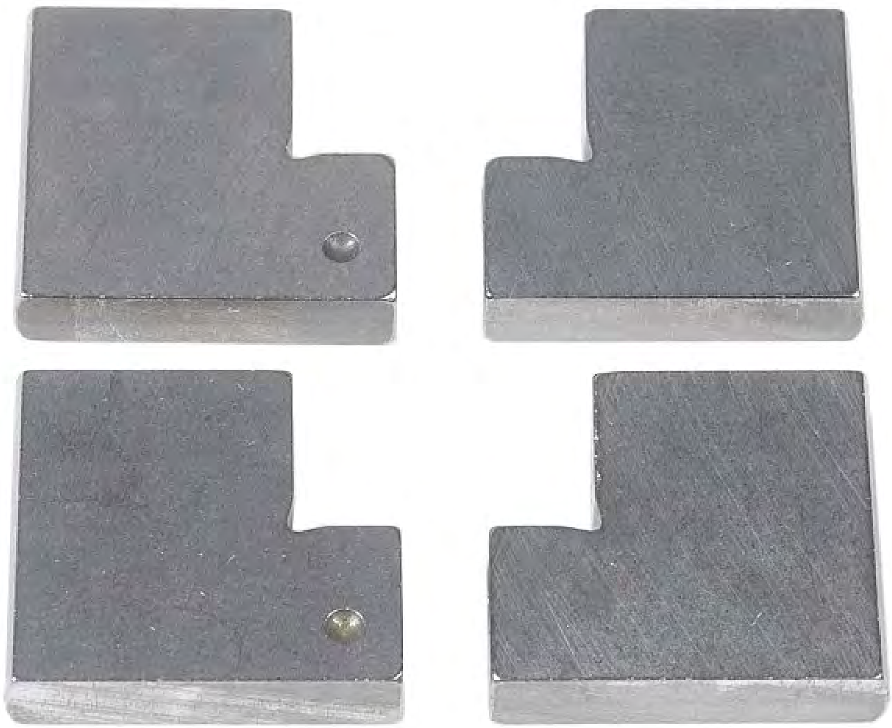
SN15382732 Drive Tang, Before

SN15382732 Drive Tang, After

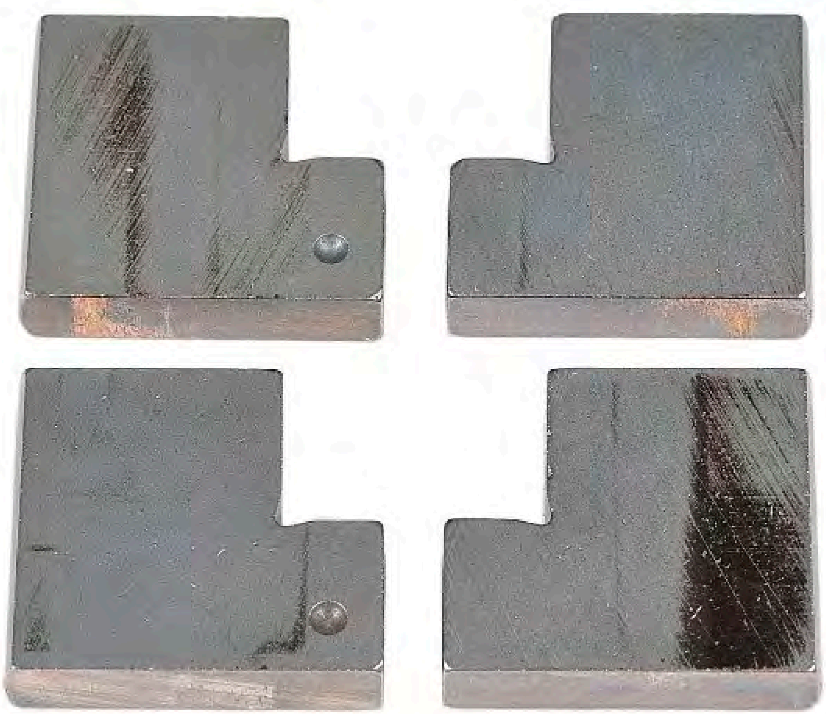


SN15282732 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



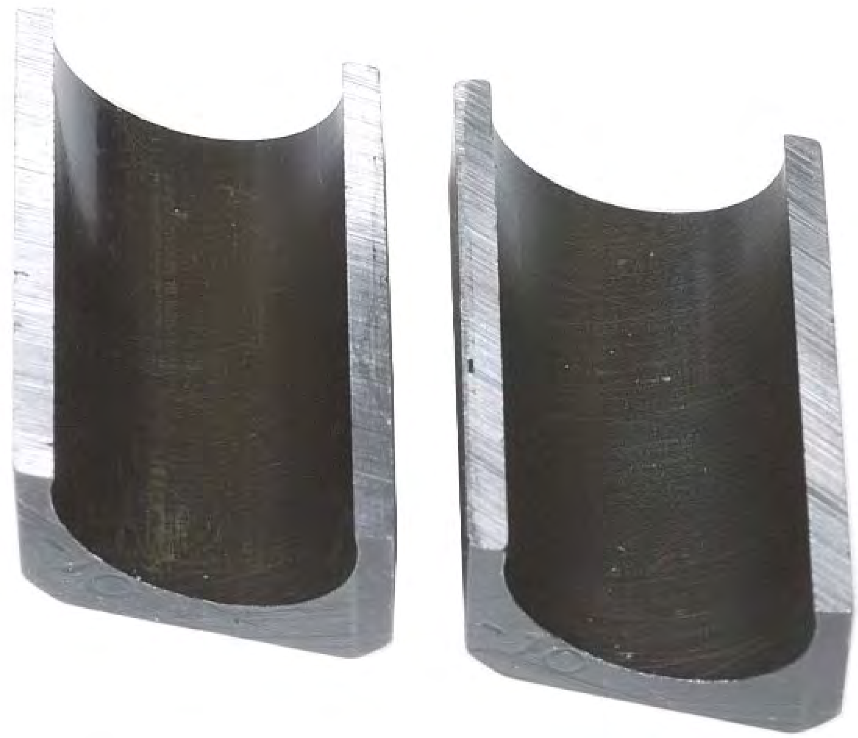
SN15382733 Transfer Pump Blades, Before



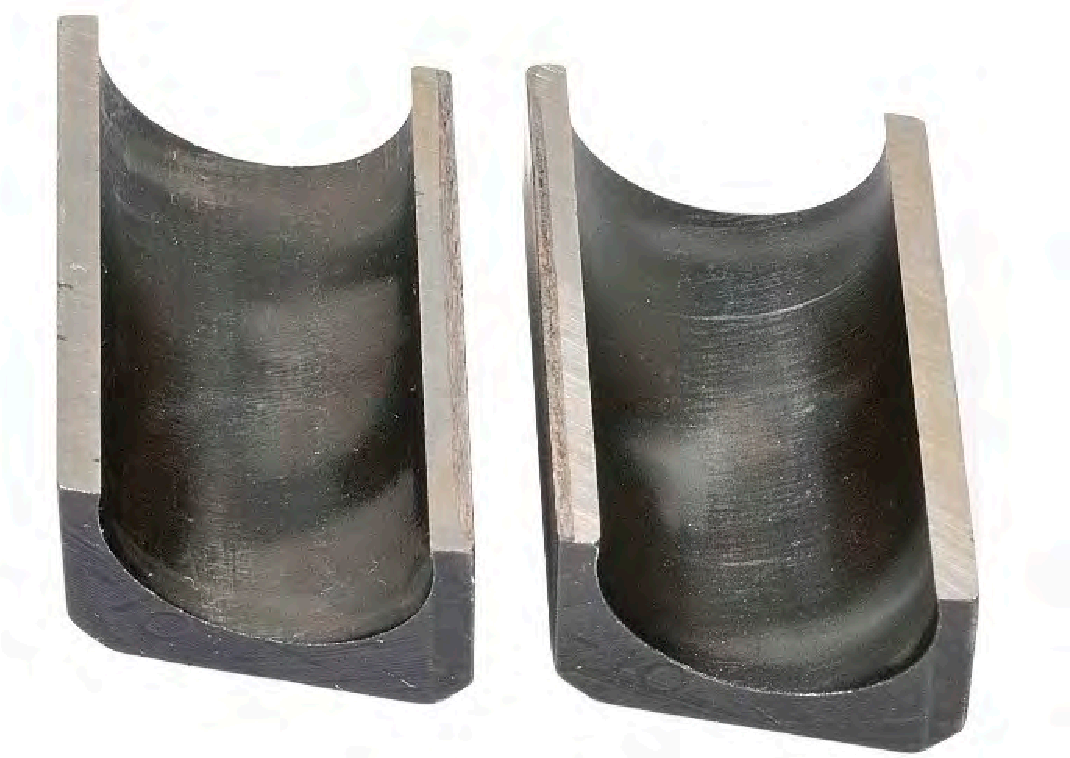
SN15382733 Transfer Pump Blades, Before

SN15382733 Transfer Pump Blades (Profile), Before

SN15382733 Transfer Pump Blades (Profile), After

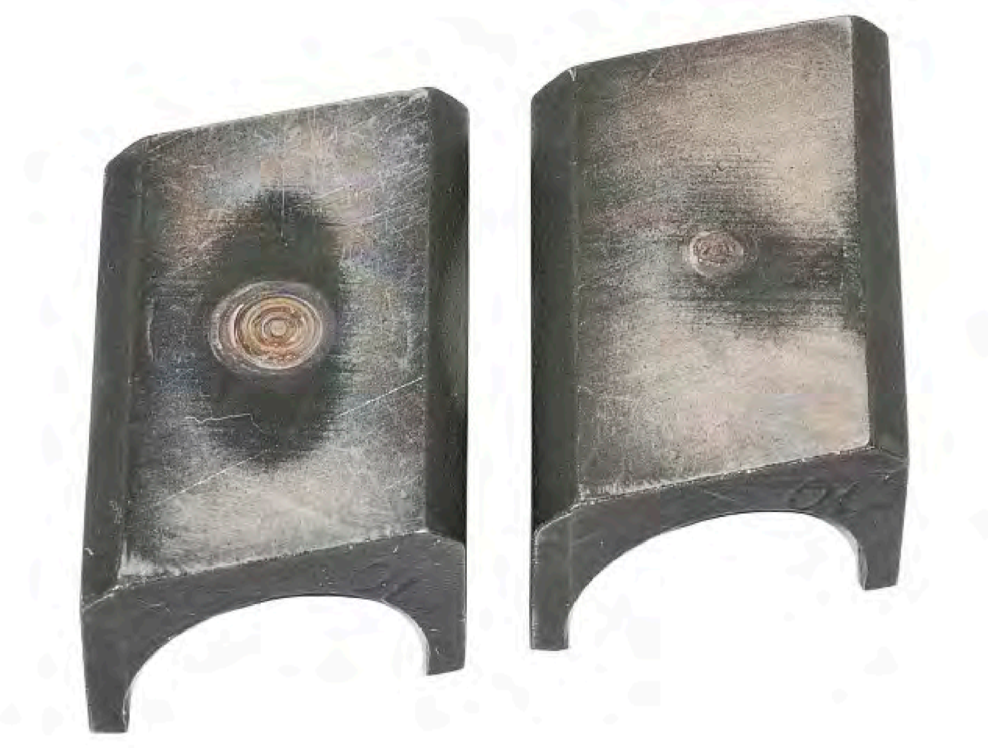


SN15382733 Shoes (Front), Before



SN15382733 Shoes (Front), After

SN15382733 Shoes (Back), Before



SN15382733 Shoes (Back), After

SN15382733 Rollers, Before

SN15382733 Rollers, After

SN15382733 Piston Plungers, Before

SN15382733 Piston Plungers, After

SN15382733 Thrust Washer, Before

SN15382733 Thrust Washer, After

SN15382733 Governor Weight, Before

SN15382733 Governor Weight, After

SN15382733 Cam Ring, Before

SN15382733 Cam Ring, After

SN15382733 Eccentric Ring, Before

SN15382733 Eccentric Ring, After

SN15382733 Rotor (Front), Before

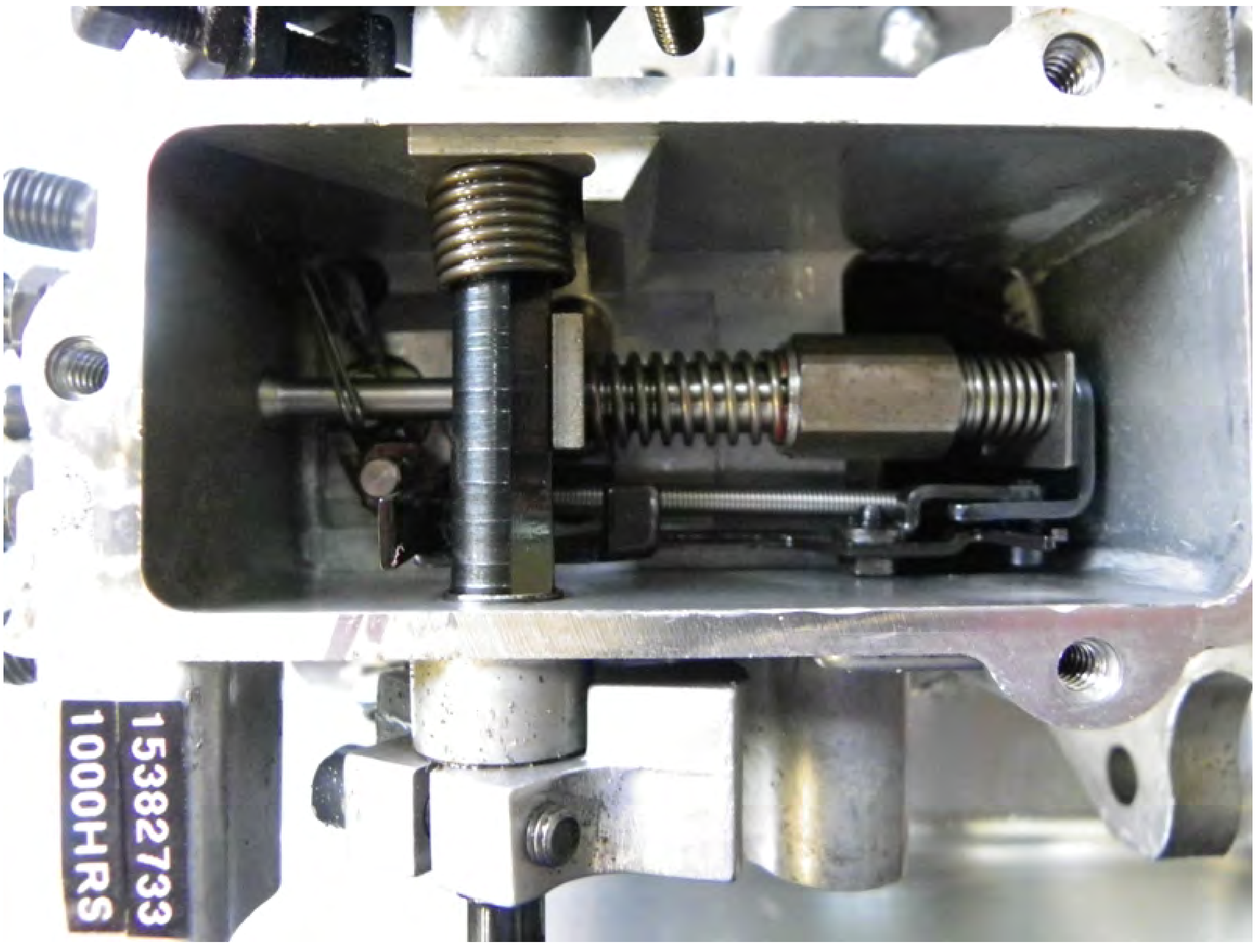
SN15382733 Rotor (Front), After


SN15382733 Rotor (Back), Before


SN15382733 Rotor (Back), After

SN15382733 Drive Tang, Before

SN15382733 Drive Tang, After



SN15282733 Governor Assembly

APPENDIX C

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Certification 2007 Diesel
Test Number: C4T3-77-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Certification 2007 Diesel
Test Fuel ID: AF 7469
Test Temperature: 77°C (170°F)
Test Number: C4T3-77-1000
Start of Test Date: November 12, 2010
End of Test Date: January 24, 2011
Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure C-1.

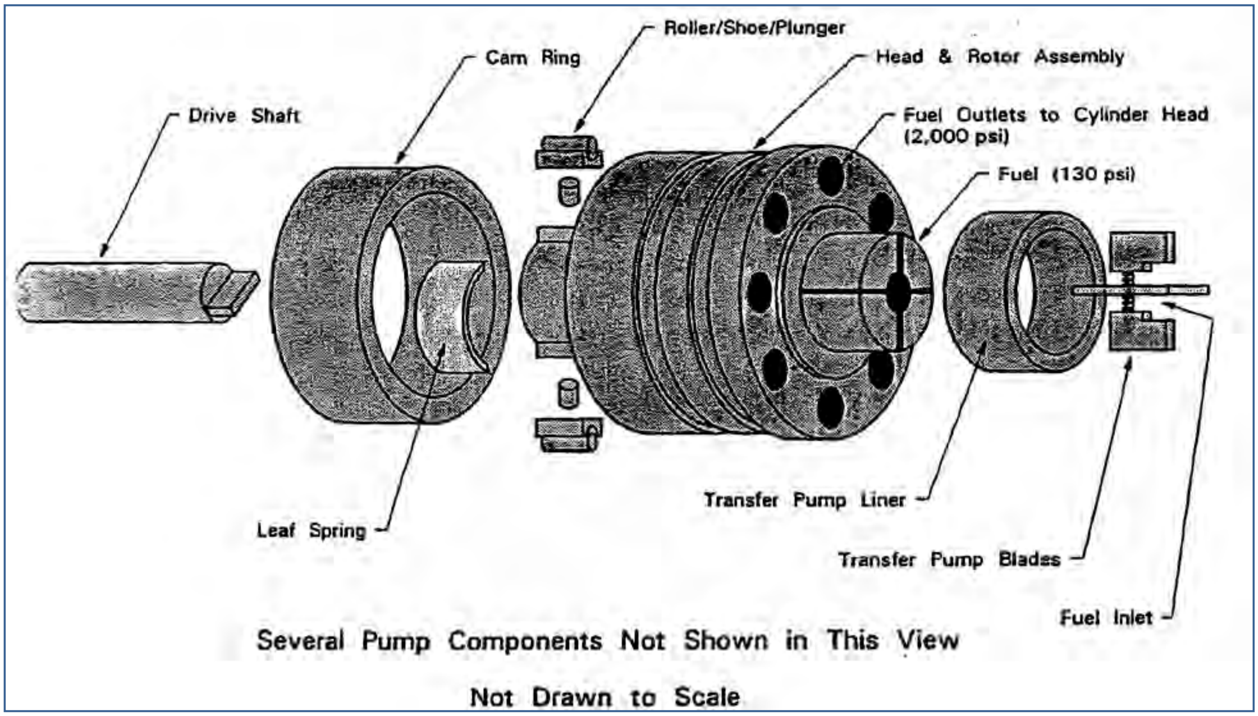


Figure C-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table C-1.

Table C-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	77 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table C-2.

Table C-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	2.71
FLO_R	Injected Flow-rate [mL/min]	789.90	15.38
FUELIN_P	Fuel Inlet Pressure [psig]	3.1	0.34
TRNS_P_R	Transfer Pump Pressure [psig]	75.0	0.54
HSG_P_R	Pump Housing Pressure [psig]	10.65	0.60
RTRN_T_R	Fuel Return Temperature [°C]	81.1	1.69
FUEL_T	Fuel Tank Temperature [°C]	25.3	5.74
FUELIN_T	Fuel Inlet Temperature [°C]	77.0	0.46

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure C-2 through Figure C-4.

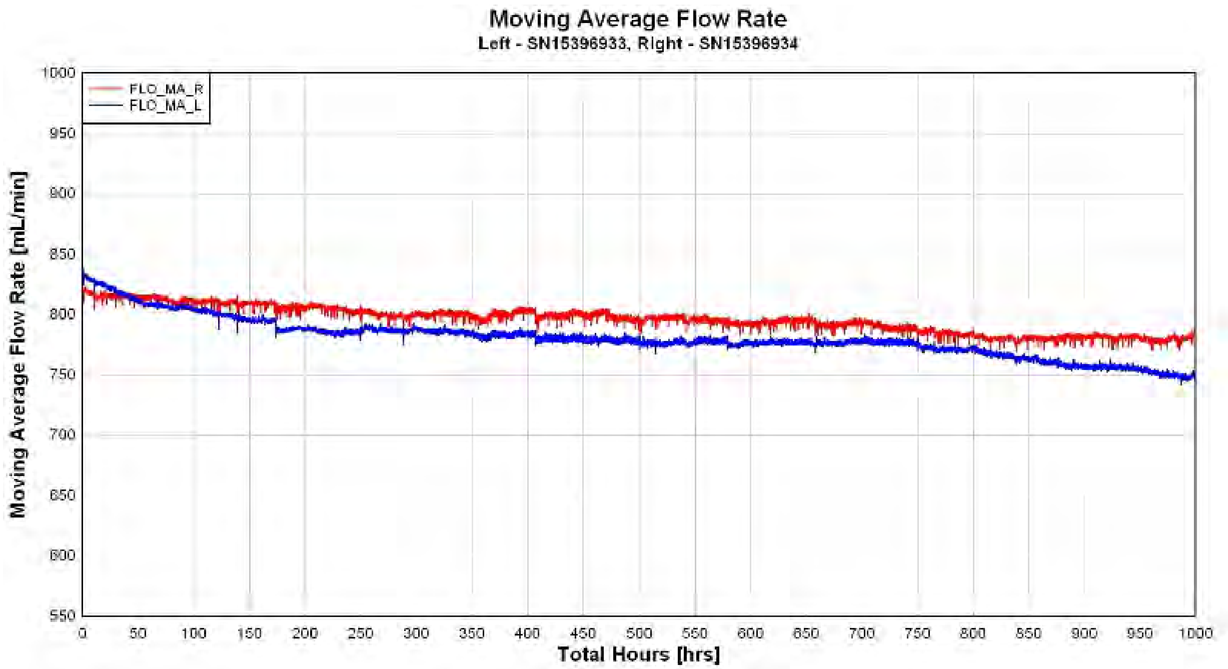


Figure C-2. Pump Flow, Moving Average

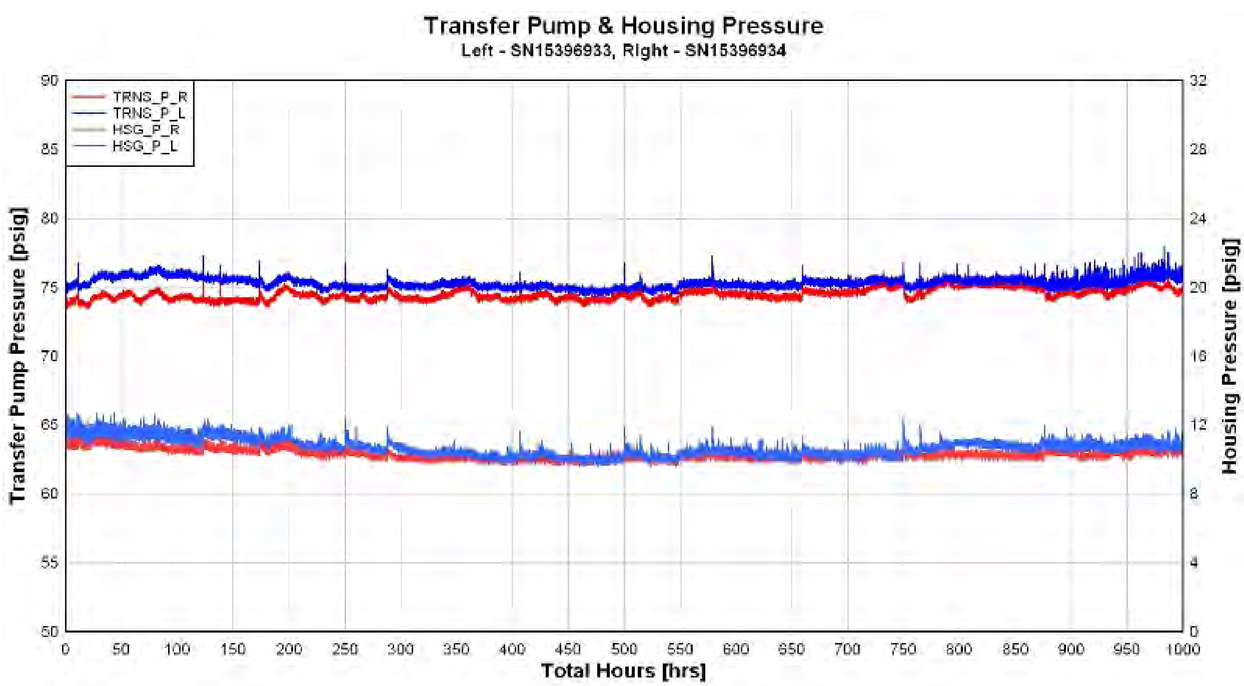


Figure C-3. Transfer Pump & Housing Pressure

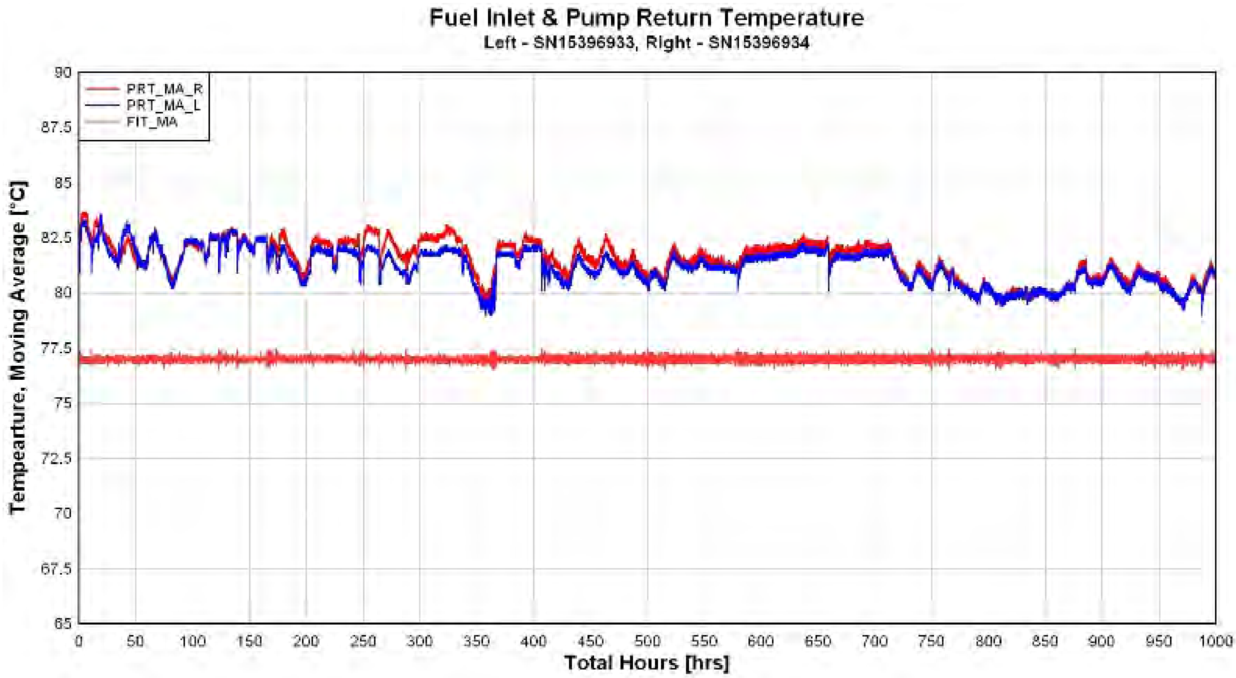


Figure C-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table C-3. (Note – Calibration data to be used as reference only)

Table C-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 3			Test Duration : 1000-hrs.		
Test Fuel : DF-2 as purchased @ 170°F				SN : 15396933			SN : 15396934		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000-hrs.*			*Pump Duration : 1000-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	62 psi	psi	62 psi	**64 psi**	-2 psi
	Return Fuel	225 cc	375 cc	290 cc	350 cc	-60 cc	300 cc	320 cc	-20 cc
350	Low Idle	12 cc	16 cc	15 cc	**7 cc**	8 cc	14 cc	**2 cc**	12 cc
	Housing psi.	8 psi	12 psi	8.0 psi	9.0 psi	-1.0 psi	9.5 psi	10.0 psi	-.5 psi
	Advance	3.50°		5.10°	5.27°	-.17°	4.10°	7.51°	-3.41°
	Cold Advance Solenoid	.0 psi	1.0 psi	.5 psi	.0 psi	.5 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	68.0 cc	.0 cc	68.0 cc	**64.0 cc**	4.0 cc
1600	WOT Fuel delivery	60 cc		65 cc	60 cc	5 cc	64 cc	60 cc	4 cc
	WOT Advance	2.50°	3.50°	3.01°	4.05°	-1.04°	3.05°	4.84°	-1.79°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	22.0 cc	.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.48°	7.07°	-.59°	6.51°	**7.60°**	-1.09°
	Low Idle	11.0°	12.0°	**10.5°**	11.1°	-.6°	11.0°	11.2°	-.2°
1825	Fuel Delivery	33 cc		39 cc	55 cc	-16 cc	39 cc	58 cc	-19 cc
1950	High Idle		15 cc	2 cc	2 cc	cc	2 cc	2 cc	0 cc
	Transfer pump psi.		125 psi	1 psi	106 psi	-105 psi	1 psi	103 psi	-102 psi
200	WOT Fuel Delivery	58 cc		62 cc	58 cc	4 cc	61 cc	**57 cc**	4 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		55 cc	50 cc	5 cc	54 cc	47 cc	7 cc
	Transfer pump psi.	16 psi		28 psi	28 psi	0 psi	31 psi	25 psi	6 psi
	Housing psi.	.0 psi	12 psi	6.0 psi	7 psi	-1 psi	7 psi	6 psi	1 psi
	Air Timing	-1.00°	.00°	-.50°	.00°	-.50°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table C-4 and Table C-5.

Table C-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396933	Test Number: 3	
Fuel Description : DF-2 as purchased @ 170°F				
	Date:	1/0/1900	4/20/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2728	3.2802	0.0074
Measurement 2		3.2728	3.2803	0.0075
Measurement 3		3.2728	3.2803	0.0075
Measurement 4		3.2728	3.2802	0.0074
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2707	3.2750	0.0043
Measurement 2		3.2706	3.2750	0.0044
Measurement 3		3.2707	3.2749	0.0042
Measurement 4		3.2707	3.2750	0.0043
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2466	3.2533	0.0067
Measurement 2		3.2467	3.2532	0.0065
Measurement 3		3.2466	3.2532	0.0066
Measurement 4		3.2464	3.2532	0.0068
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2054	3.2116	0.0062
Measurement 2		3.2056	3.2115	0.0059
Measurement 3		3.2052	3.2116	0.0064
Measurement 4		3.2053	3.2115	0.0062
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2728	3.2803	0.0074
Transfer Pump Blade 2		3.2707	3.2750	0.0043
Transfer Pump Blade 3		3.2466	3.2532	0.0067
Transfer Pump Blade 4		3.2054	3.2116	0.0062
	Roller to Roller (in)	1.9760	1.9740	-0.0020
	Eccentricity (in.)	0.0080	0.0050	-0.0030
	Drive Backlash (In)	0.0040	0.0040	0.0000

Table C-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		**SN: 15396934**	**Test Number: 3**	
Fuel Description : DF-2 as purchased @ 170°F				
	Date:	1/0/1900	4/19/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2497	3.2527	0.0030
Measurement 2		3.2499	3.2527	0.0028
Measurement 3		3.2497	3.2527	0.0030
Measurement 4		3.2498	3.2526	0.0028
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2505	3.2517	0.0012
Measurement 2		3.2505	3.2515	0.0010
Measurement 3		3.2503	3.2515	0.0012
Measurement 4		3.2505	3.2514	0.0009
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2532	3.2578	0.0046
Measurement 2		3.2533	3.2575	0.0042
Measurement 3		3.2531	3.2577	0.0046
Measurement 4		3.2531	3.2576	0.0045
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2706	3.2693	-0.0013
Measurement 2		3.2703	3.2693	-0.0010
Measurement 3		3.2704	3.2692	-0.0012
Measurement 4		3.2703	3.2692	-0.0011
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2498	3.2527	0.0029
Transfer Pump Blade 2		3.2505	3.2515	0.0011
Transfer Pump Blade 3		3.2532	3.2577	0.0045
Transfer Pump Blade 4		3.2704	3.2693	-0.0012
	Roller to Roller (in)	1.9760	1.9732	-0.0028
	Eccentricity (in.)	0.0110	0.0110	0.0000
	Drive Backlash (In)	0.0035	0.0040	0.0005

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table C-6.

Table C-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
3	15396933	DF-2 as purchased @ 170°F	3-1	2075	1950	Pass	Pass	Pass	Pass	Pass	Pass
			3-2	2175	1950	Pass	Pass	Pass	Pass	Pass	Pass
			3-3	2100	1975	Pass	Pass	Pass	Pass	Pass	Pass
			3-4	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			3-5	2150	1850	Pass	Pass	Pass	Pass	Pass	Pass
			3-6	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			3-7	2175	1975	Pass	Pass	Pass	Pass	Pass	Pass
			3-8	2175	1900	Pass	Pass	Pass	Pass	Pass	Pass
3	15396934	DF-2 as purchased @ 170°F	3-11	2075	1725	Pass	Fail	Pass	Pass	Pass	Pass
			3-12	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			3-13	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			3-14	2150	2000	Pass	Pass	Pass	Pass	Pass	Pass
			3-15	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			3-16	2125	1975	Pass	Pass	Pass	Pass	Pass	Pass
			3-17	2200	1850	Pass	Fail	Pass	Pass	Pass	Pass
			3-18	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 14 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table C-7 and Table C-8.

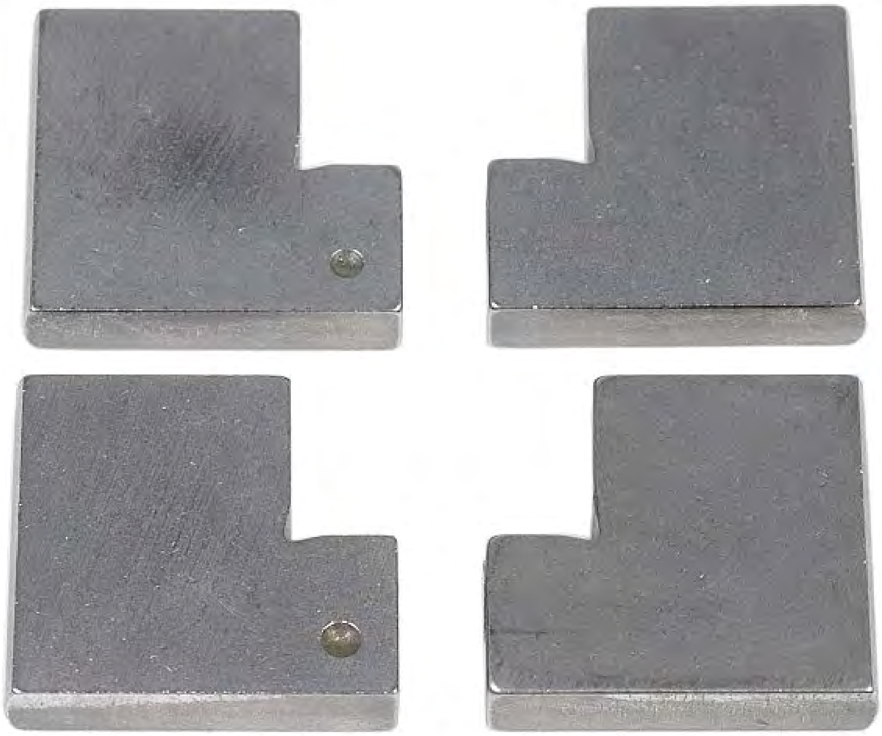
Table C-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15396933
Test Condition : DF-2 as purchased @ 170°F		Pump Duration : 1000-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Polishing wear at rotor slots ans liner contact	1.5
BLADE SPRINGS	No wear	0
LINER	Polishing wear 80% of surface	1.5
TRANSFER PUMP REGULATOR	Light wear mark from rotor contact. Metal flakes on screen	1
REGULATOR PISTON	Black coating. Light polihing in spots	0.5
ROTOR	No wear	0
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Scuffed on one side	3
PLUNGERS	Lightly polished in spots	1
SHOES	Small dimple on left shoe only	1.5
ROLLERS	Darker in color. Normal wear	1
LEAF SPRING	Very light wear from shoe contact	1
CAM RING	Normal polishing from cam ring	1
THRUST WASHER	Light polishing at weight contact	1
THRUST SLEEVE	Normal wear marks from governor pivot fingers	1
GOVORNER WEIGHTS	Light wear from T- washer contact	1
LINK HOOK	All pumps have some degree of wearon governor arm from pivot pin	1
METERING VAVLE	Very light polishing wear	0.5
DRIVE SHAFT TANG	Light polihing marks	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	In spec, normal	1
ADVANCE PISTON	Scuffing wear at top, right side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.130

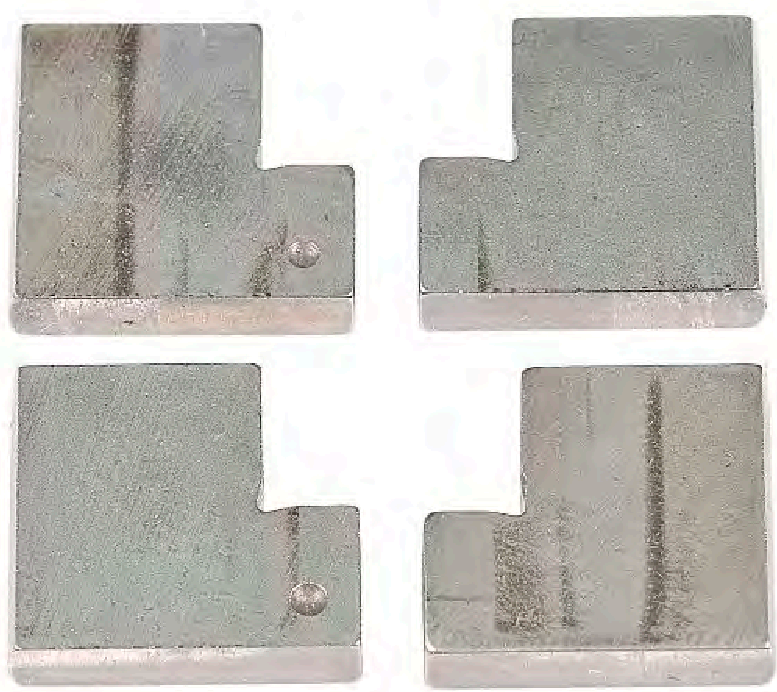
Table C-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15396934
Test Condition : DF-2 as purchased @ 170°F		Pump Duration : 1000-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Polishing wear	1
BLADE SPRINGS	No wear	0
LINER	Polishing wear	1
TRANSFER PUMP REGULATOR	Light wear mark from rotor contact. Metal flakes on screen	1
REGULATOR PISTON	Black coating. Light polishing in spots	1.5
ROTOR	No wear	1
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Scuffed on one side	1
PLUNGERS	Lightly polished in spots	1
SHOES	Light Polishing wear	1
ROLLERS	Normal	1
LEAF SPRING	Very light wear from shoe contact	1
CAM RING	Normal polishing from cam ring	1
THRUST WASHER	Light polishing at weight contact	1
THRUST SLEEVE	Normal wear marks from governor pivot fingers	1
GOVORNER WEIGHTS	Light wear from T- washer contact	1
LINK HOOK	All pumps have some degree of wearon governor arm from pivot pin	1
METERING VAVLE	Very light polishing wear	0.5
DRIVE SHAFT TANG	Light polihing marks	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	In spec, normal	1
ADVANCE PISTON	Scuffing wear at top, right side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.065

PHOTOGRAPHS FOR LEFT PUMP



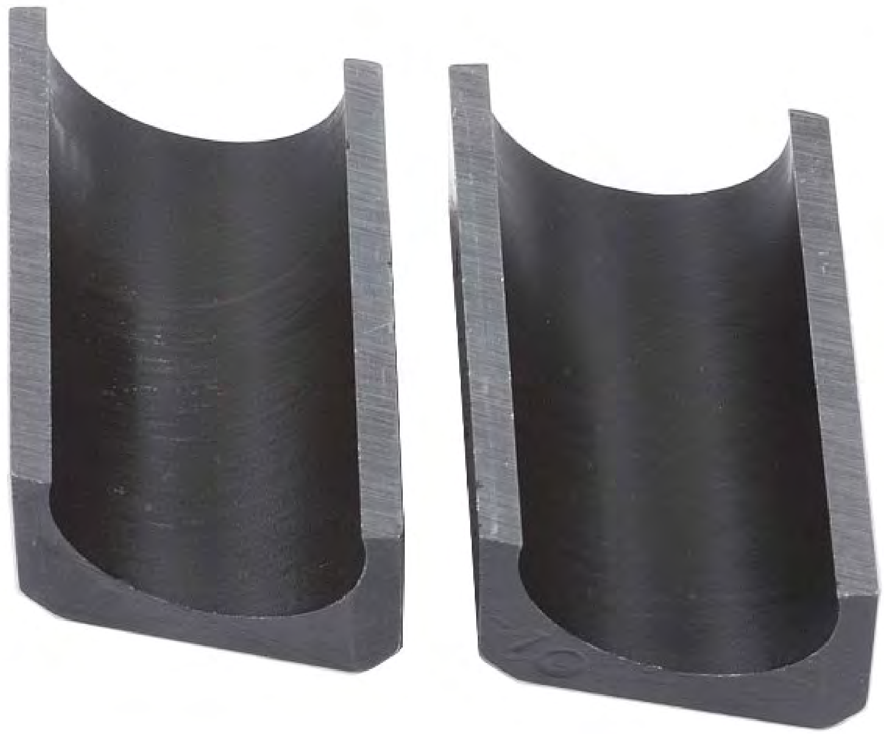
SN15396933 Transfer Pump Blades (Side), Before



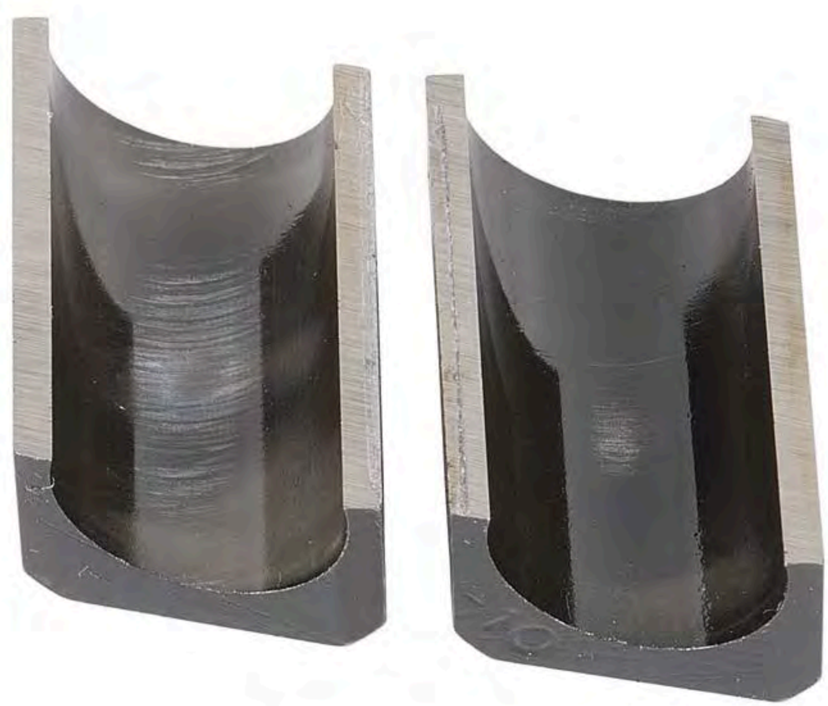
SN15396933 Transfer Pump Blades (Side), After

SN15396933 Transfer Pump Blades (Profile), Before

SN15396933 Transfer Pump Blades (Profile), After



SN15396933 Shoes (Front), Before



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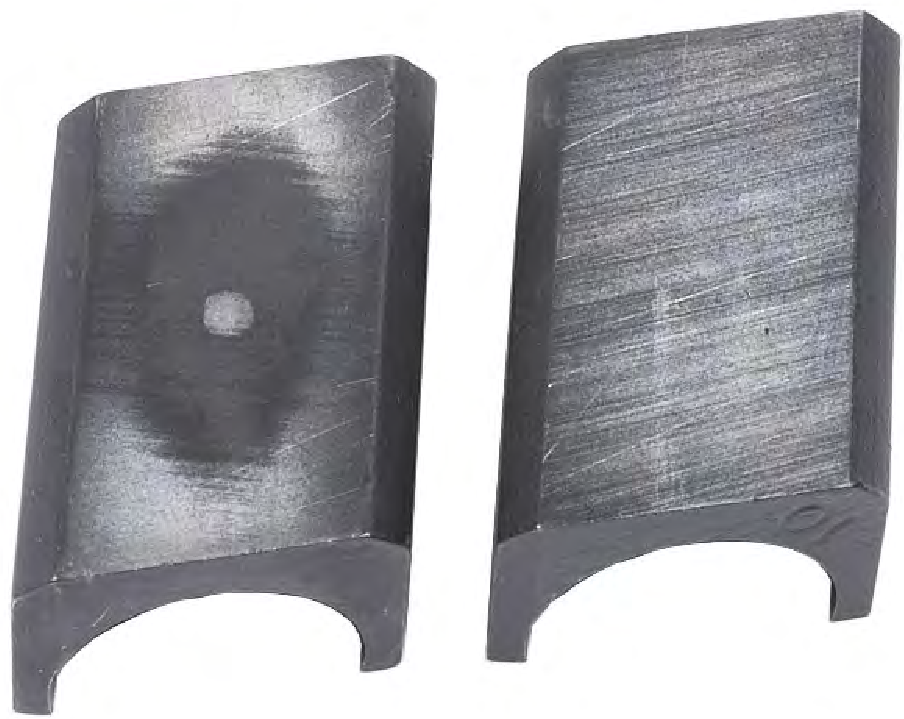

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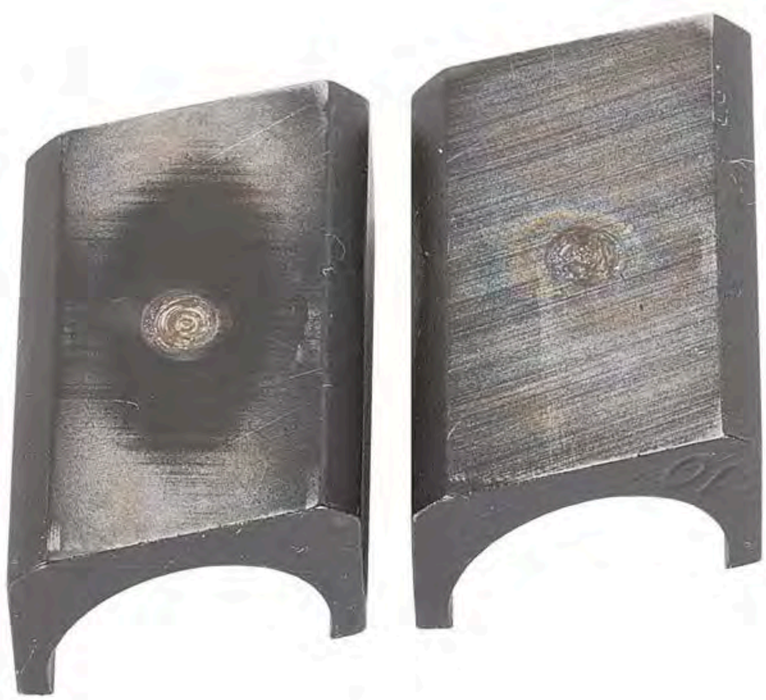


SN15396933 Shoes (Back), After

SN15396933 Rollers, Before

SN15396933 Rollers, After

SN15396933 Piston Plungers, Before

SN15396933 Piston Plungers, After

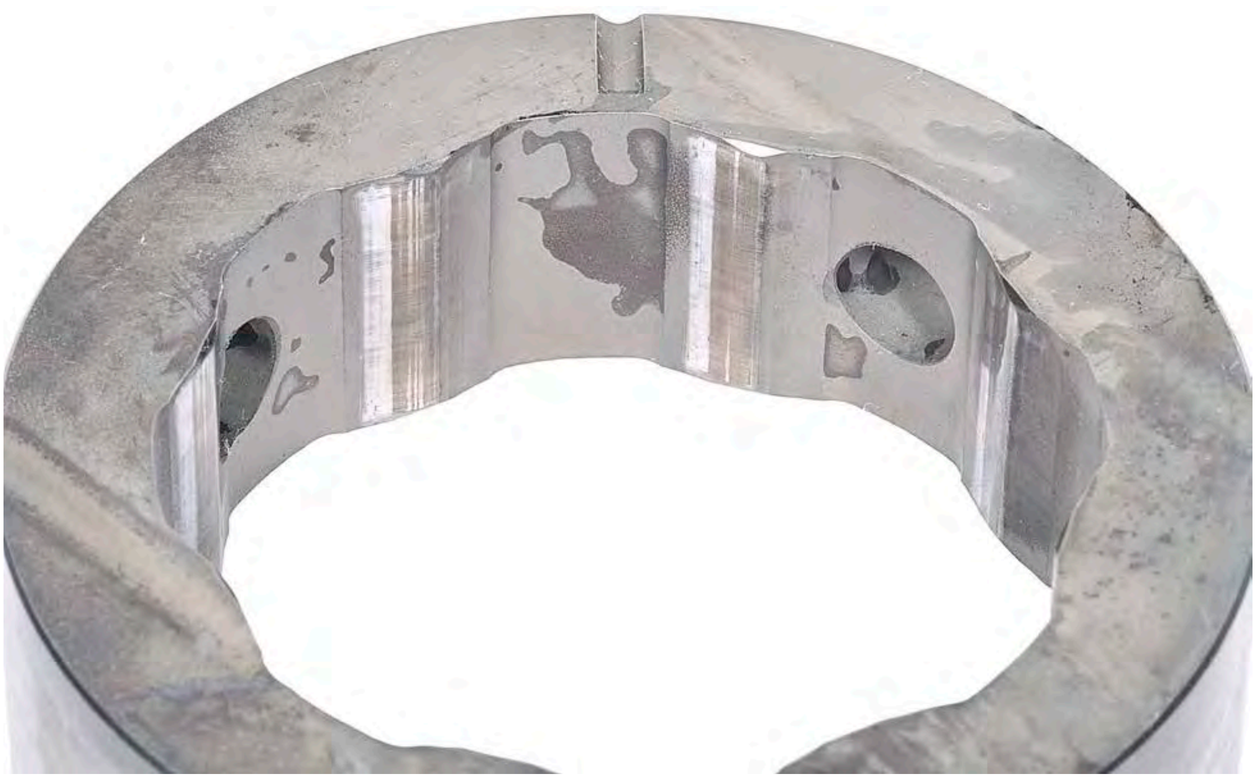
SN15396933 Thrust Washer, Before

SN15396933 Thrust Washer, After

SN15396933 Governor Weight, Before

SN15396933 Governor Weight, After

SN15396933 Cam Ring, Before



SN15396933 Cam Ring, After

SN15396933 Eccentric Ring, Before

SN15396933 Eccentric Ring, After

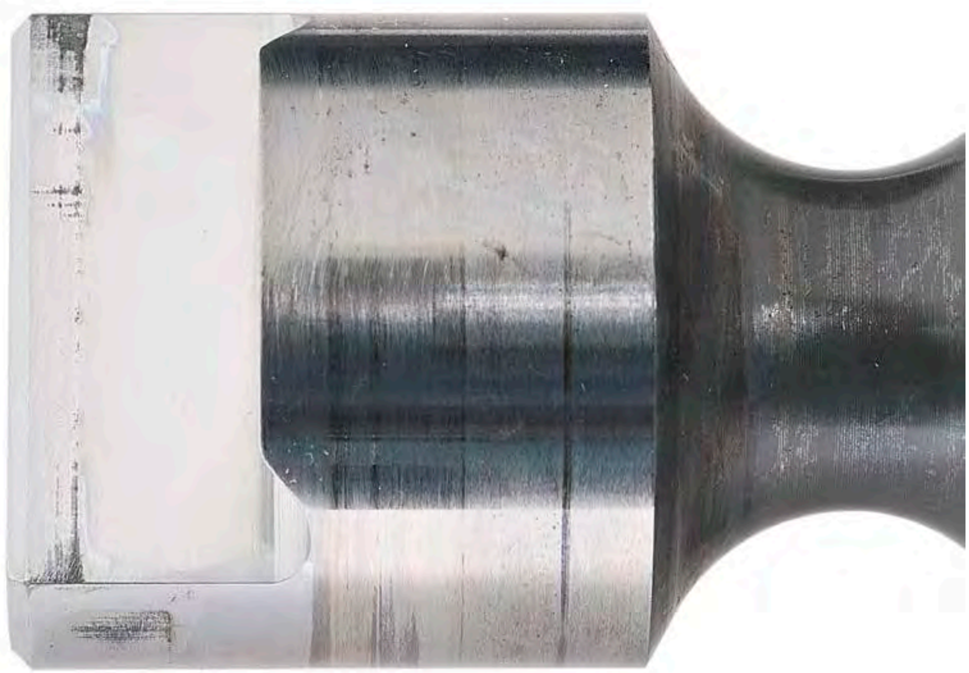
SN15396933 Rotor (Front), Before

SN15396933 Rotor (Front), After

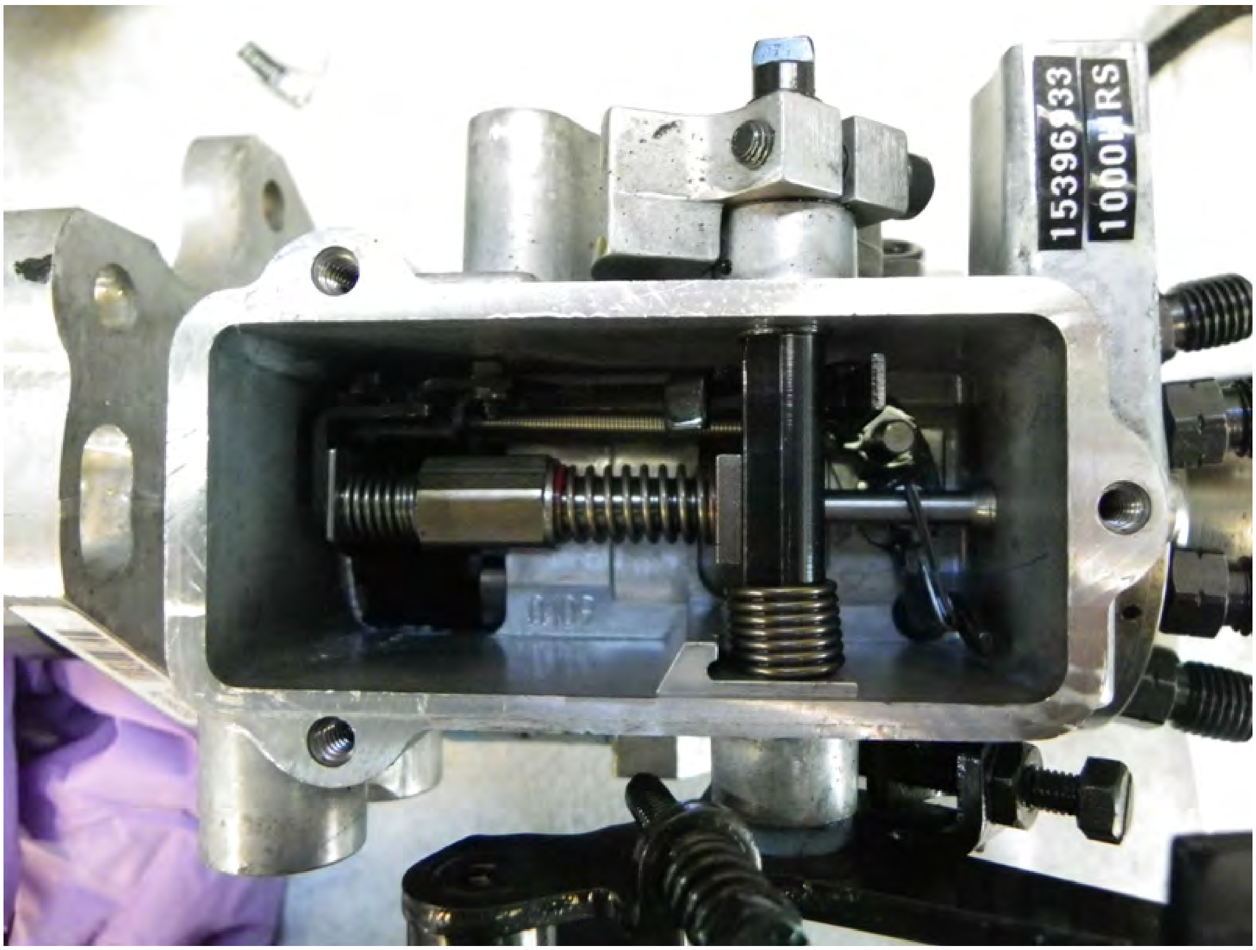
SN15396933 Rotor (Back), Before

SN15396933 Rotor (Back), After

SN15396933 Drive Tang, Before

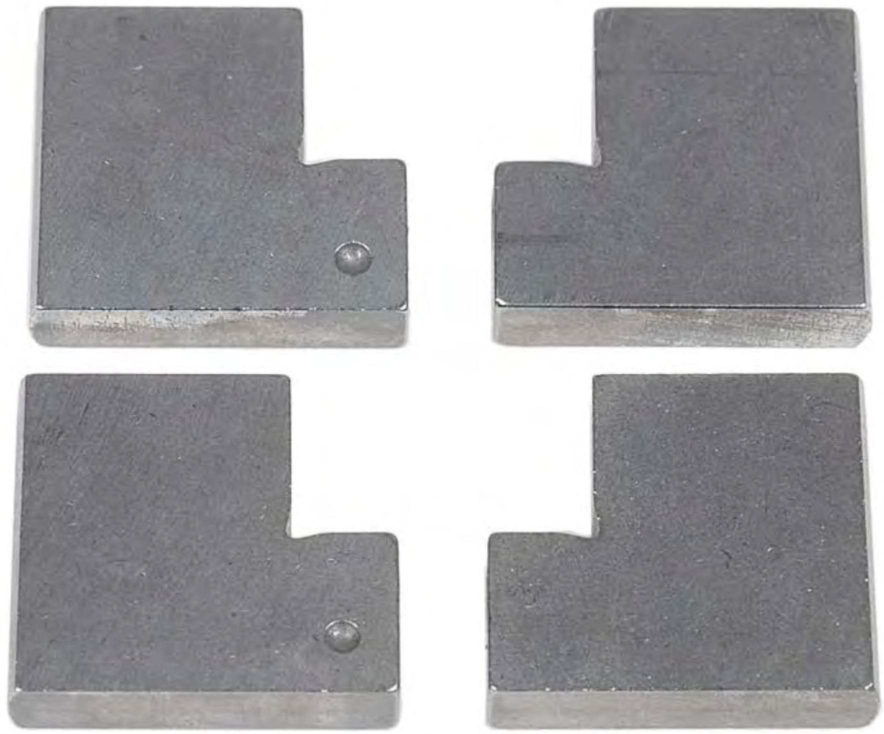


SN15396933 Drive Tang, After

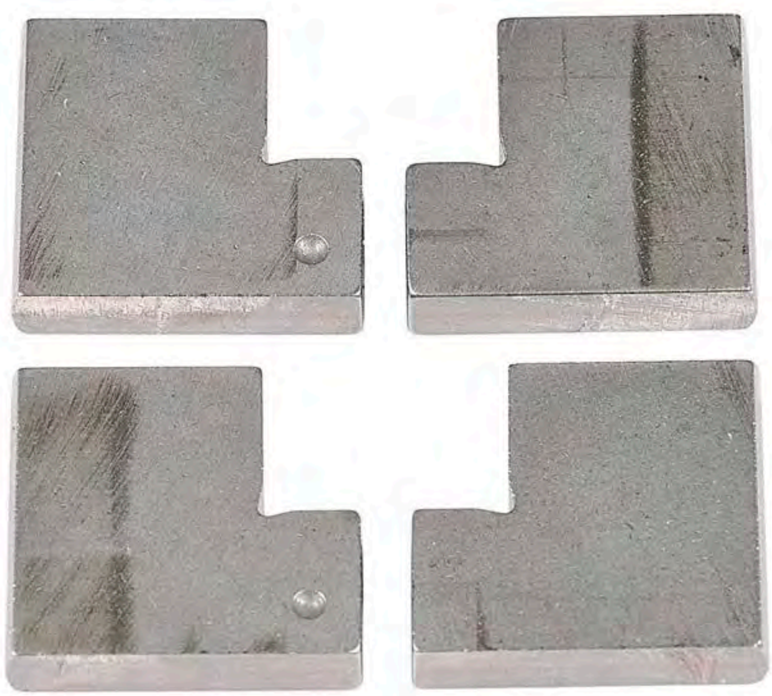


SN15396933 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



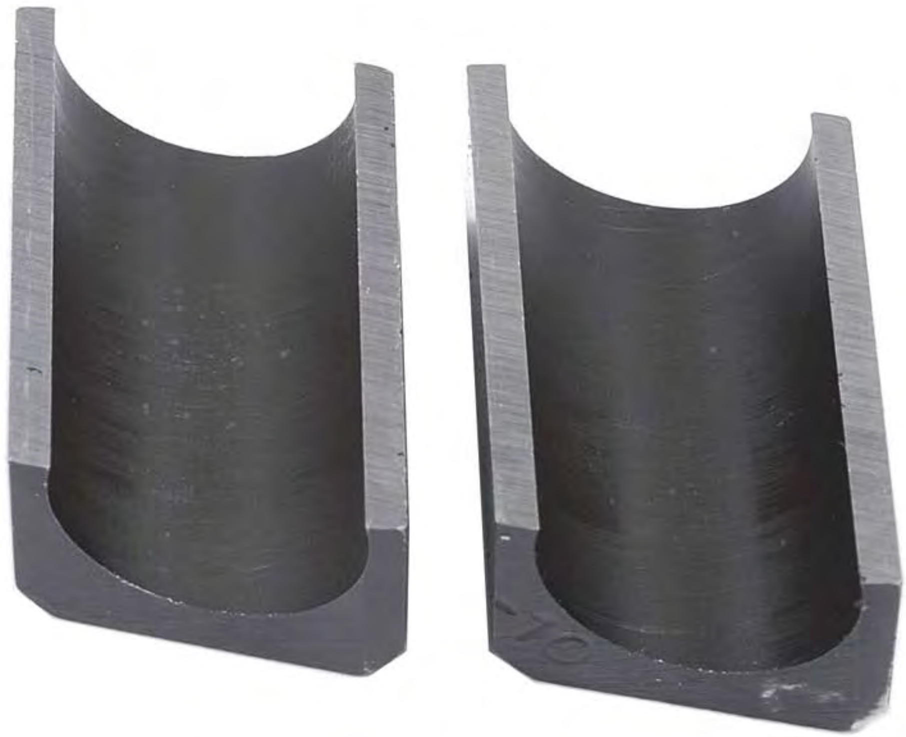
SN15396934 Transfer Pump Blades, Before



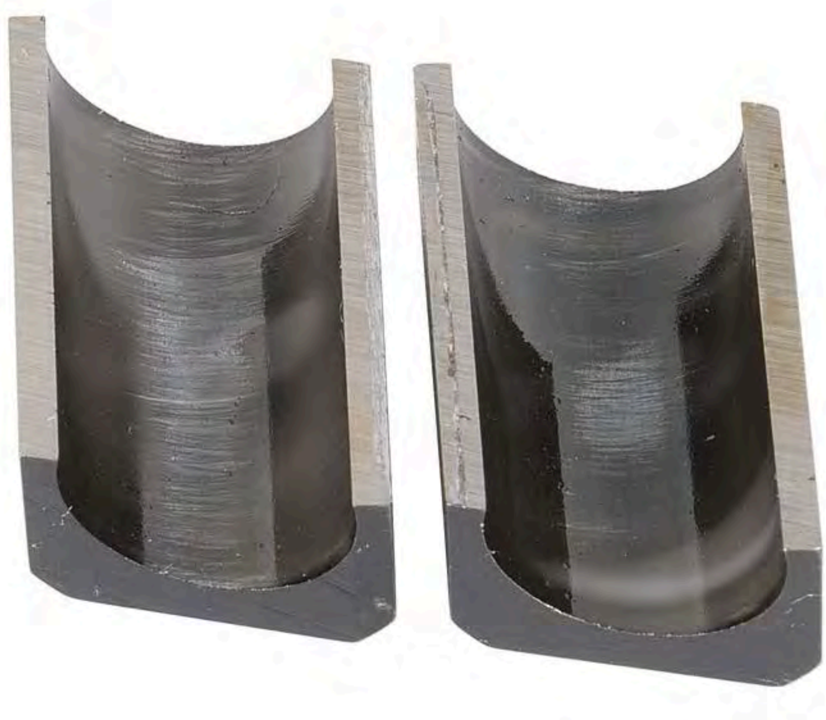
SN15396934 Transfer Pump Blades, After

SN15396934 Transfer Pump Blades (Profile), Before

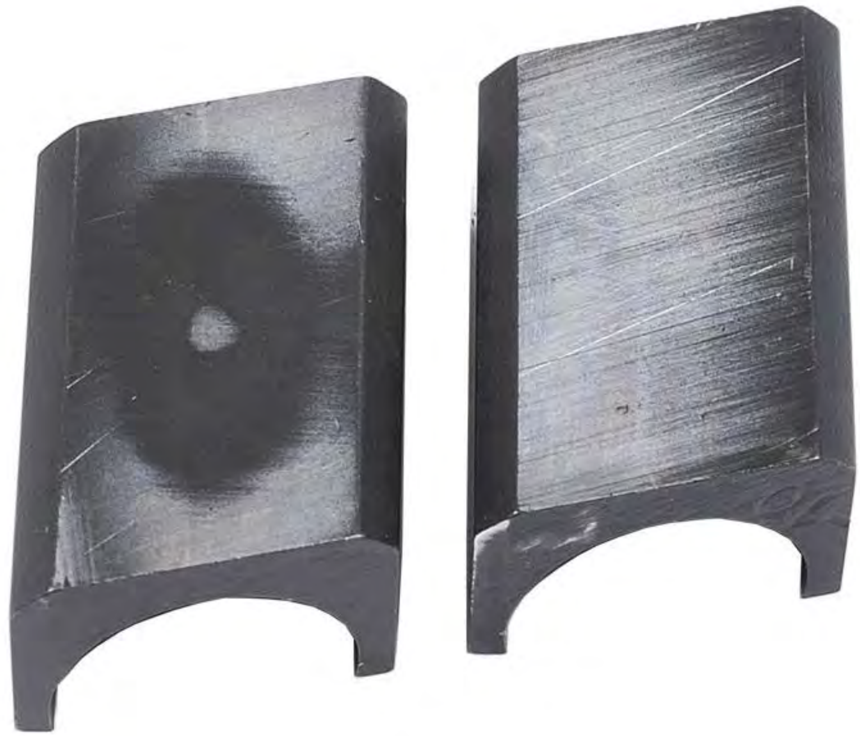
SN15396934 Transfer Pump Blades (Profile), After



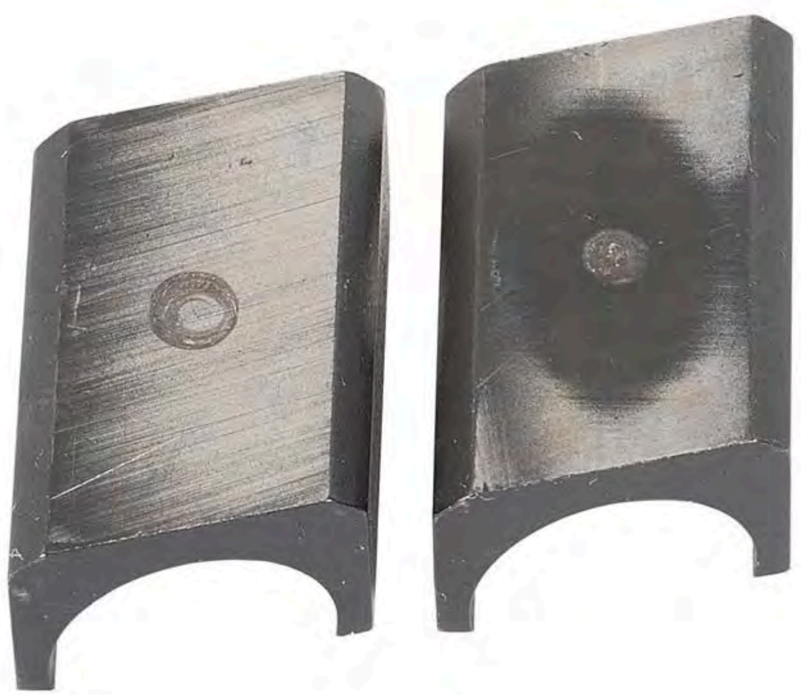
SN15396934 Shoes (Front), Before



SN15396934 Shoes (Front), After

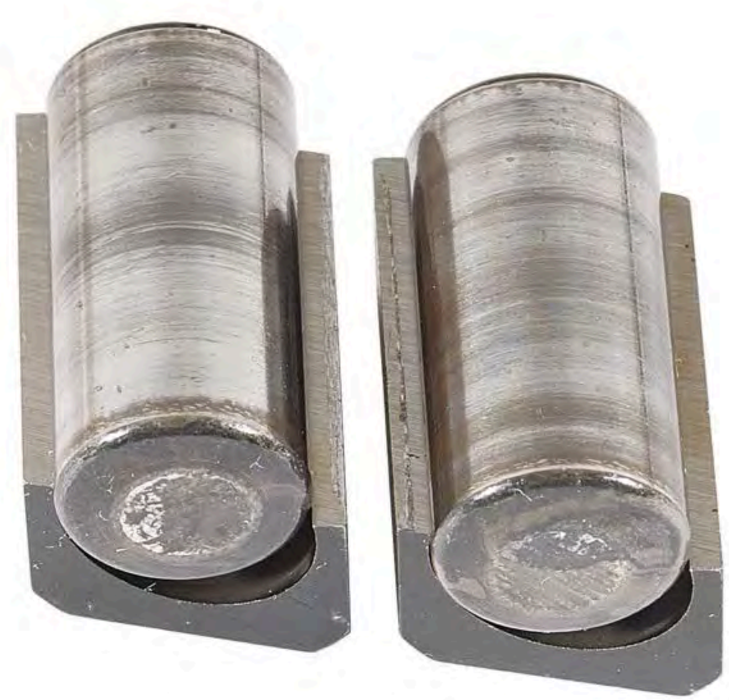


SN15396934 Shoes (Back), Before



SN15396934 Shoes (Back), After

SN15396934 Rollers, Before



SN15396934 Rollers, After

SN15396934 Piston Plungers, Before

SN15396934 Piston Plungers, After

SN15396934 Thrust Washer, Before

SN15396934 Thrust Washer, After

SN15396934 Governor Weight, Before

SN15396934 Governor Weight, After

SN15396934 Cam Ring, Before

SN15396934 Cam Ring, After

SN15396934 Eccentric Ring, Before

SN15396934 Eccentric Ring, After

SN15396934 Rotor (Front), Before

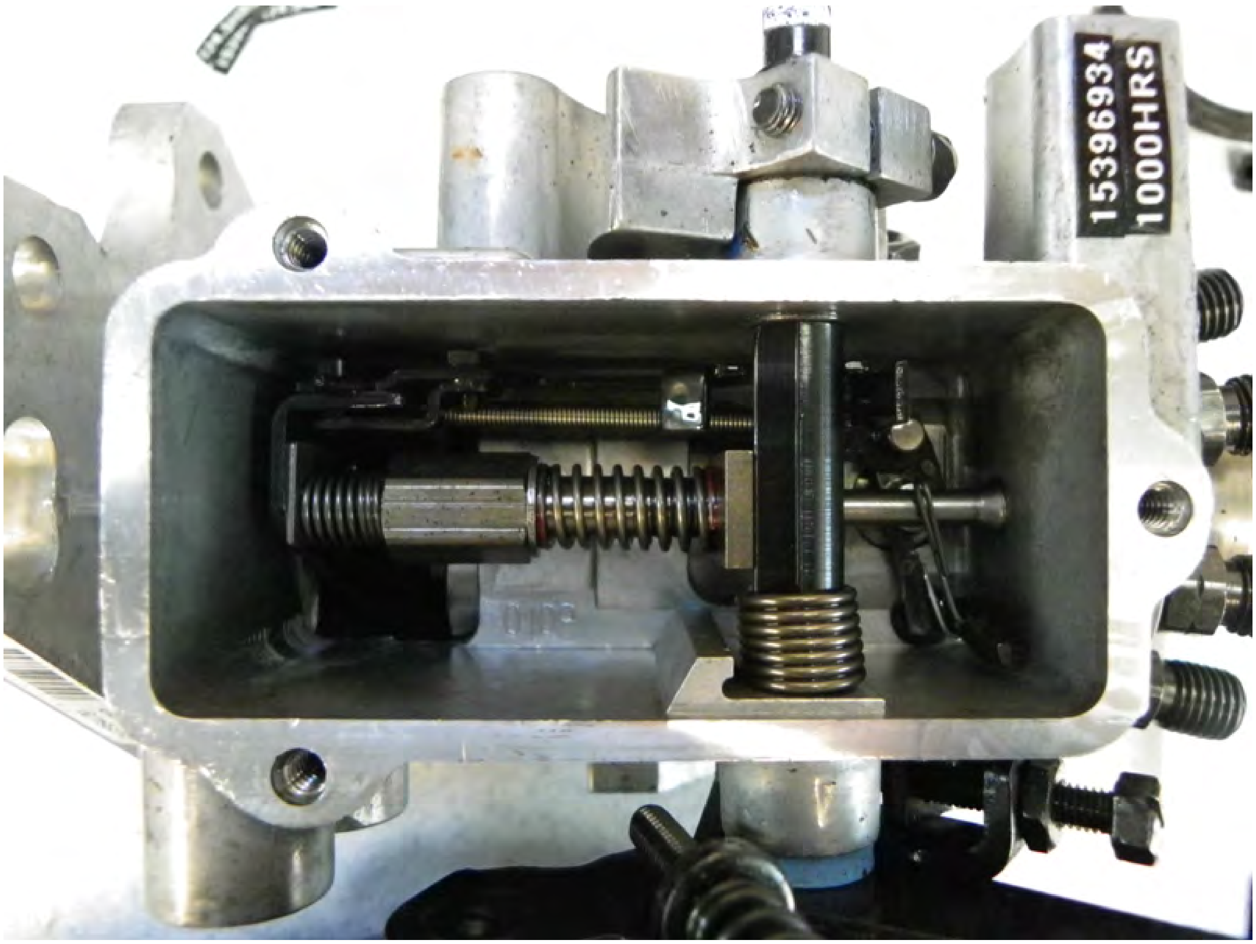
SN15396934 Rotor (Front), After

SN15396934 Rotor (Back), Before

SN15396934 Rotor (Back), After

SN15396934 Drive Tang, Before

SN15396934 Drive Tang, After



SN15396934 Governor Assembly

APPENDIX D

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Certification 2007 Diesel (Clay Treated)
Test Number: C3T4-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Certification 2007 Diesel (Clay Treated)

Test Fuel ID: CL 10-1388

Test Temperature: 40°C (104°F)

Test Number: C3T4-40-1000

Start of Test Date: September 21, 2010

End of Test Date: December 28, 2010

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure D-1.

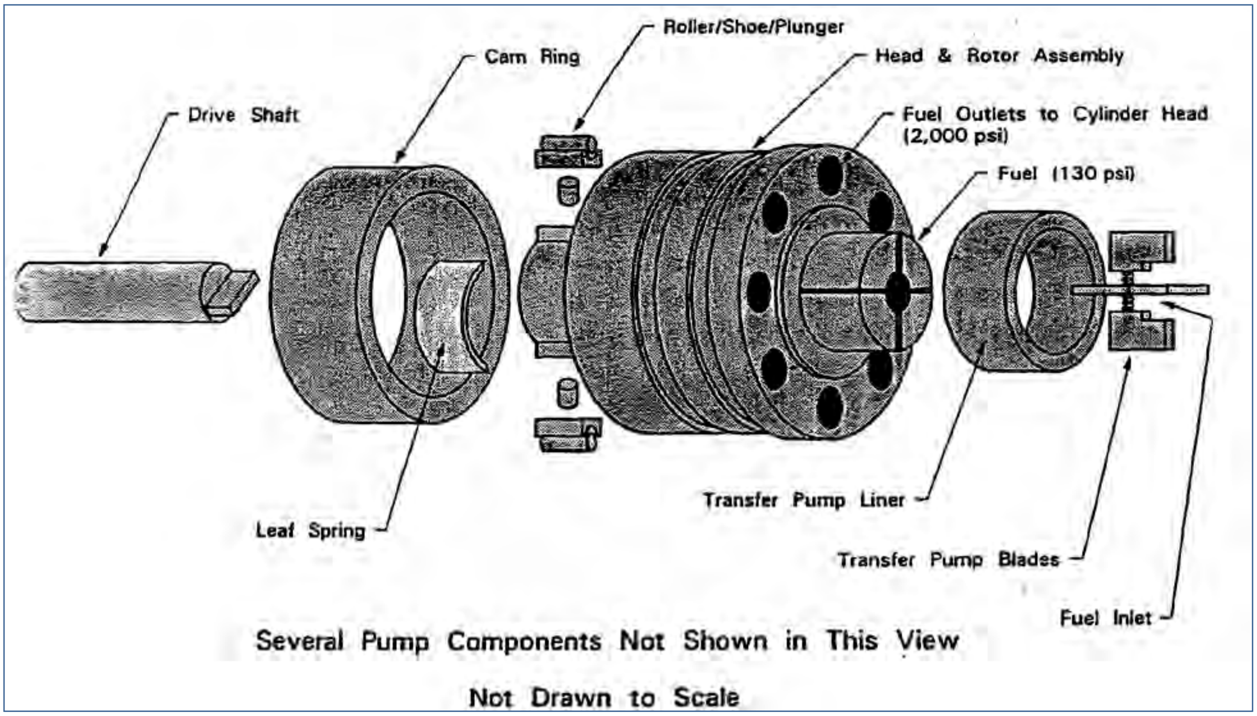


Figure D-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table D-1.

Table D-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table D-2.

Table D-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.20
FLO_R	Injected Flow-rate [mL/min]	836.55	23.26
FUELIN_P	Fuel Inlet Pressure [psig]	3	0.28
TRNS_P_R	Transfer Pump Pressure [psig]	73.9	1.96
HSG_P_R	Pump Housing Pressure [psig]	1210	1.61
RTRN_T_R	Fuel Return Temperature [°C]	81.1	1.69
FUEL_T	Fuel Tank Temperature [°C]	29.3	3.36
FUELIN_T	Fuel Inlet Temperature [°C]	40.0	0.91

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure D-2 through Figure D-4.

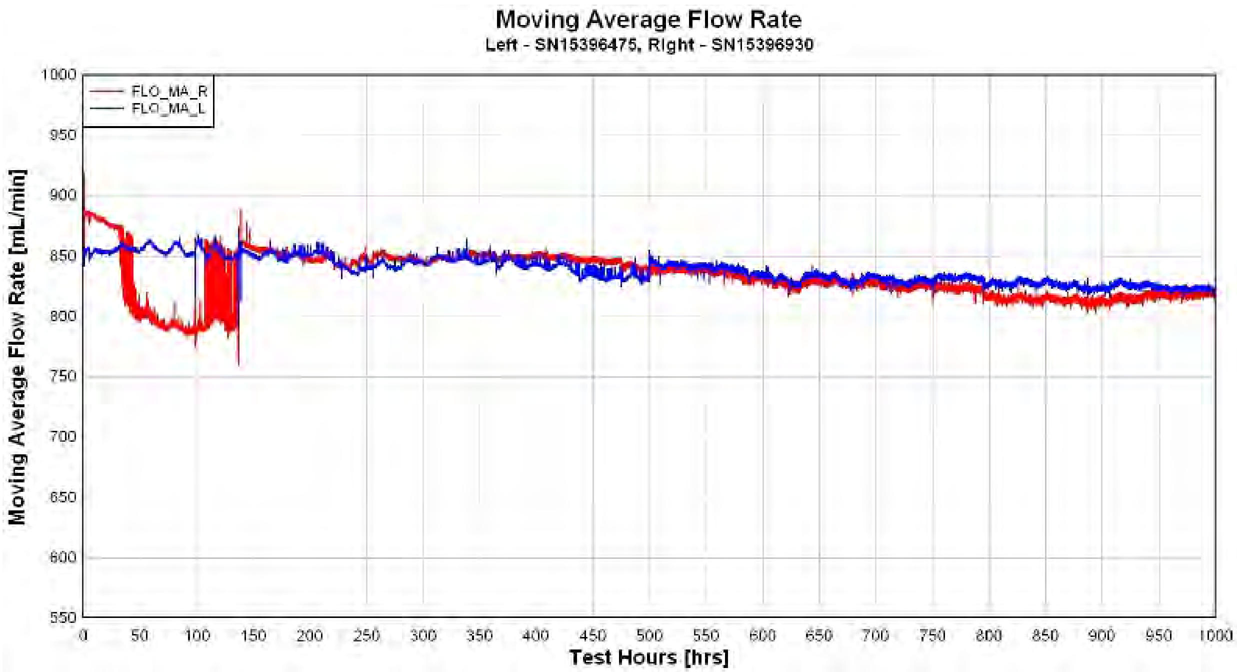


Figure D-2. Pump Flow, Moving Average

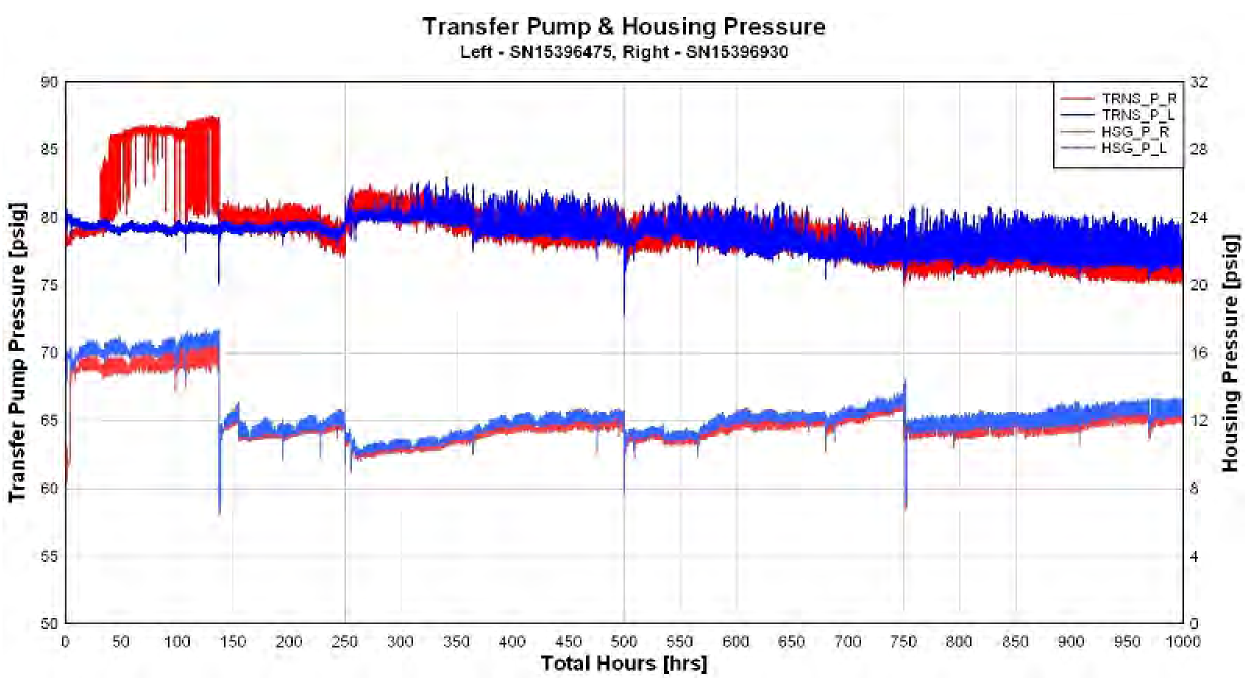


Figure D-3. Transfer Pump & Housing Pressure

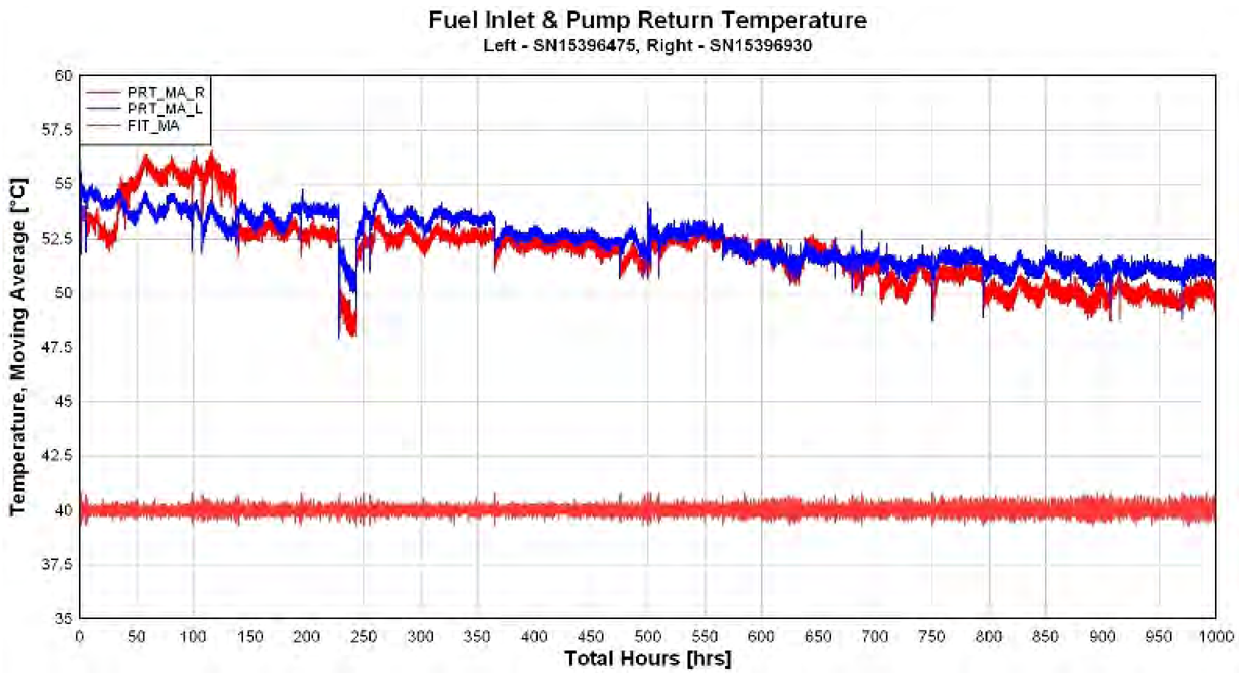


Figure D-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table D-3. (Note – Calibration data to be used as reference only)

Table D-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 4			Test Duration : 1000-hrs.		
Test Fuel : DF-2 Clay Treated @ 105°F				SN : 15396475			SN : 15396930		
PUMP RPM	***Description***	***Specification***		***Pump Duration : 1000-hrs.***			***Pump Duration : 1000-hrs.***		
		Min	***Max***	***Before***	***After***	***Change***	***Before***	***After***	***Change***
1000	Transfer pump psi.	60 psi	62 psi	62 psi	60 psi	2 psi	62 psi	**64 psi**	-2 psi
	Return Fuel	225 cc	375 cc	280 cc	300 cc	-20 cc	290 cc	310 cc	-20 cc
350	Low Idle	12 cc	16 cc	14 cc	14 cc	0 cc	14 cc	**2 cc**	12 cc
	Housing psi.	8 psi	12 psi	10.0 psi	10.0 psi	.0 psi	10.0 psi	9.0 psi	1.0 psi
	Advance	3.50°		4.17°	**2.37°**	1.80°	4.52°	4.70°	-.18°
	Cold Advance Solenoid	.0 psi	1.0 psi	.5 psi	.0 psi	.5 psi	1.0 psi	.0 psi	1.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.5 cc	.5 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	**65.0 cc**	3.0 cc	68.0 cc	**66.0 cc**	2.0 cc
1600	WOT Fuel delivery	60 cc		64 cc	62 cc	2 cc	67 cc	63 cc	4 cc
	WOT Advance	2.50°	3.50°	2.94°	2.20°	.74°	2.63°	2.02°	.61°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	22.0 cc	.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.63°	6.98°	-.35°	5.76°	5.50°	.26°
	Low Idle	11.0°	12.0°	11.0°	11.1°	.0°	11.0°	11.0°	.0°
1825	Fuel Delivery	33 cc		38 cc	60 cc	-22 cc	38 cc	58 cc	-20 cc
1950	High Idle		15 cc	2 cc	2 cc	cc	1 cc	2 cc	-1 cc
	Transfer pump psi.		125 psi	107 psi	107 psi	0 psi	101 psi	104 psi	-3 psi
200	WOT Fuel Delivery	58 cc		64 cc	60 cc	4 cc	63 cc	59 cc	4 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		56 cc	49 cc	7 cc	54 cc	49 cc	5 cc
	Transfer pump psi.	16 psi		27 psi	25 psi	2 psi	16 psi	19 psi	-3 psi
	Housing psi.	.0 psi	12 psi	6.0 psi	8 psi	-2 psi	7 psi	7 psi	0 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table D-4 and Table D-5.

Table D-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396475	Test Number: 4	
Fuel Description : DF-2 Clay Treated @ 105°F				
	Date:	4/28/2010	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2642	3.2592	-0.0050
Measurement 2		3.2640	3.2592	-0.0048
Measurement 3		3.2640	3.2593	-0.0047
Measurement 4		3.2641	3.2592	-0.0049
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.1951	3.1908	-0.0043
Measurement 2		3.1951	3.1907	-0.0044
Measurement 3		3.1950	3.1907	-0.0043
Measurement 4		3.1950	3.1907	-0.0043
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2585	3.2567	-0.0018
Measurement 2		3.2583	3.2566	-0.0017
Measurement 3		3.2583	3.2567	-0.0016
Measurement 4		3.2585	3.2566	-0.0019
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2601	3.2583	-0.0018
Measurement 2		3.2600	3.2582	-0.0018
Measurement 3		3.2599	3.2577	-0.0022
Measurement 4		3.2600	3.2579	-0.0021
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2641	3.2592	-0.0049
Transfer Pump Blade 2		3.1951	3.1907	-0.0043
Transfer Pump Blade 3		3.2584	3.2567	-0.0017
Transfer Pump Blade 4		3.2600	3.2580	-0.0020
	Roller to Roller (in)	1.9760	1.9745	-0.0015
	Eccentricity (in.)	0.0080	0.0120	0.0040
	Drive Backlash (In)	0.0040	0.0065	0.0025

Table D-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396930	Test Number: 4	
Fuel Description : DF-2 Clay Treated @ 105°F				
	Date:	4/28/2010	9/26/1902	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2777	3.2783	0.0006
Measurement 2		3.2778	3.2783	0.0005
Measurement 3		3.2777	3.2783	0.0006
Measurement 4		3.2778	3.2783	0.0005
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2697	3.2678	-0.0019
Measurement 2		3.2698	3.2680	-0.0018
Measurement 3		3.2698	3.2679	-0.0019
Measurement 4		3.2698	3.2680	-0.0018
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2451	3.2469	0.0018
Measurement 2		3.2450	3.2468	0.0018
Measurement 3		3.2450	3.2468	0.0018
Measurement 4		3.2450	3.2469	0.0019
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2431	3.2423	-0.0008
Measurement 2		3.2431	3.2421	-0.0010
Measurement 3		3.2431	3.2423	-0.0008
Measurement 4		3.2431	3.2423	-0.0008
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2778	3.2783	0.0006
Transfer Pump Blade 2		3.2698	3.2679	-0.0019
Transfer Pump Blade 3		3.2450	3.2469	0.0018
Transfer Pump Blade 4		3.2431	3.2423	-0.0008
	Roller to Roller (in)	1.9760	1.9745	-0.0015
	Eccentricity (in.)	0.0040	0.0060	0.0020
	Drive Backlash (In)	0.0040	0.0065	0.0025

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table D-6.

Table D-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation

6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
4	15396475	DF-2 Clay Treated @ 105°F	4-1	2100	2000	Pass	Pass	Pass	Pass	Pass	Pass
			4-2	2175	2000	Pass	Pass	Pass	Pass	Pass	Pass
			4-3	2075	1900	Pass	Pass	Pass	Pass	Pass	Pass
			4-4	2175	1900	Pass	Pass	Pass	Pass	Pass	Pass
			4-5	2125	1900	Pass	Pass	Pass	Pass	Pass	Pass
			4-6	2150	1975	Pass	Pass	Pass	Pass	Pass	Pass
			4-7	2150	1975	Pass	Pass	Pass	Pass	Pass	Pass
			4-8	2125	*1900*	Pass	Pass	Pass	Fail	Pass	Fail
4	15396930	DF-2 Clay Treated @ 105°F	4-11	2150	1900	Pass	Pass	Pass	Pass	Pass	Pass
			4-12	2175	1975	Pass	Pass	Pass	Pass	Pass	Pass
			4-13	2150	1750	Pass	Pass	Pass	Pass	Pass	Pass
			4-14	2200	1975	Pass	Pass	Pass	Pass	Pass	Pass
			4-15	2100	1800	Pass	Pass	Pass	Pass	Pass	Pass
			4-16	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			4-17	2150	1775	Pass	Pass	Pass	Pass	Pass	Pass
			4-18	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 15 out of 16								

Comments : 4-8 Has a cracked inlet. Could not get an accurate assessment.

DF2 Clay Treated @ 105° F

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table D-7 and Table D-8.

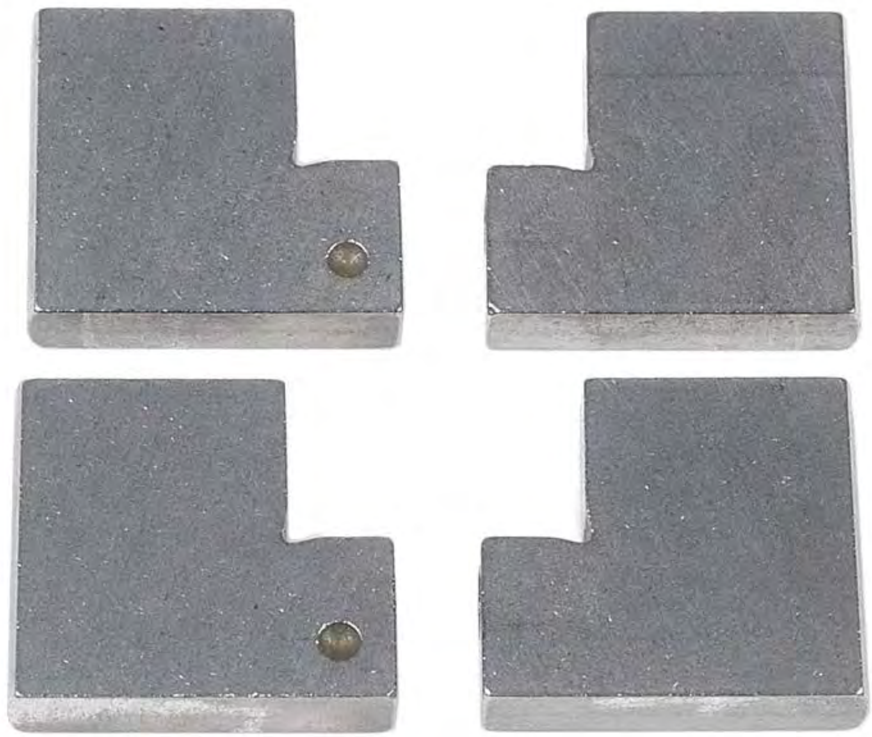
Table D-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079 (arctic)		SN: 15396475
Test Condition : DF-2 Clay Treated @ 105°F		Pump Duration : 1000-hrs.
Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Medium wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Normal	1
LINER	Light Polishing	1
TRANSFER PUMP REGULATOR	Wear mark from rotor contact	1
REGULATOR PISTON	Polishing wear	1.5
ROTOR	Normal	1
ROTOR RETAINERS	Wear mark from rotor contact. Some debris on screen.	1.5
DELIVERY VALVE	Polishing wear	1.5
PLUNGERS	Polishing wear and light scorring	3
SHOES	Large dimples from plungers. Scratches from rollers and light wear from leaf spring.	3.5
ROLLERS	Polishing wear and some discoleration	1.5
LEAF SPRING	Light wear at shoe contact	1
CAM RING	Light Polishing wear	1
THRUST WASHER	Groove worn by weights	2.5
THRUST SLEEVE	Wear spots from linkage hooks	1
GOVORNER WEIGHTS	Wear at foot from thrust washer contact	1.5
LINK HOOK	Light wear at pivot and hook	1
METERING VAVLE	Very light polishing wear	1
DRIVE SHAFT TANG	Wear from rotor contact	1.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Fretting wear on top side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.543

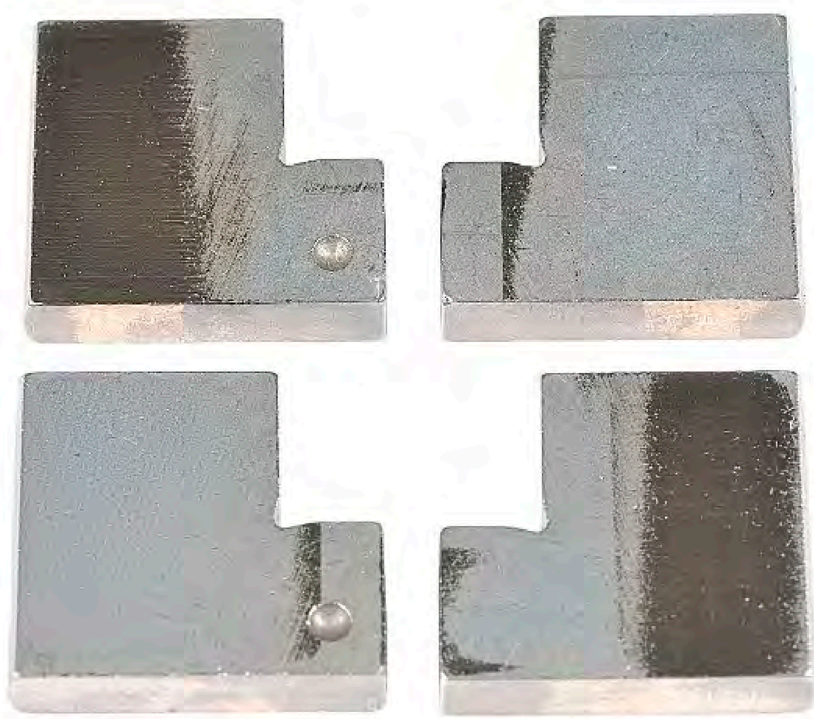
Table D-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079 (arctic)		SN: 15396930
Test Condition : DF-2 Clay Treated @ 105°F		Pump Duration : 1000-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Medium wear at rotor slots and liner contact	2.5
BLADE SPRINGS	One broken	4
LINER	Polishing wear	1.5
TRANSFER PUMP REGULATOR	Wear mark from rotor contact	1.5
REGULATOR PISTON	Polishing wear	1.5
ROTOR	Wear ring at distributor port area	1.5
ROTOR RETAINERS	Wear mark from rotor contact	2
DELIVERY VALVE	Polishing wear	1.5
PLUNGERS	Polishing wear	1.5
SHOES	Large dimples from plungers. Scratches from rollers and light wear from leaf spring.	2.5
ROLLERS	Good. Slightly darker than BOT	1
LEAF SPRING	Light wear at shoe contact	1
CAM RING	Light polishing wear	1
THRUST WASHER	Polishing wear from weights	1.5
THRUST SLEEVE	Wear spots from linkage hook	1
GOVORNER WEIGHTS	Wear at front foot from thrust washer contact	1.5
LINK HOOK	Light wear on pivot and hook	1
METERING VAVLE	Very light polishing wear	0.5
DRIVE SHAFT TANG	Wear from rotor contact	1.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scuffing wear at top right side	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.565

PHOTOGRAPHS FOR LEFT PUMP

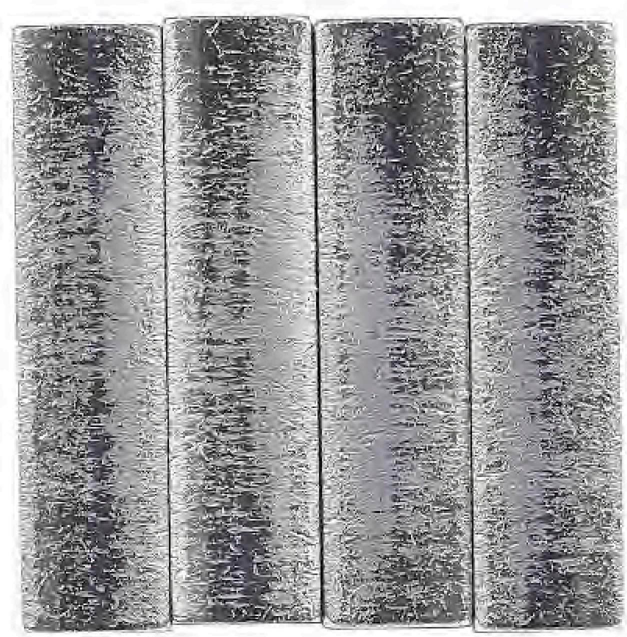


SN15396475 Transfer Pump Blades (Side), Before

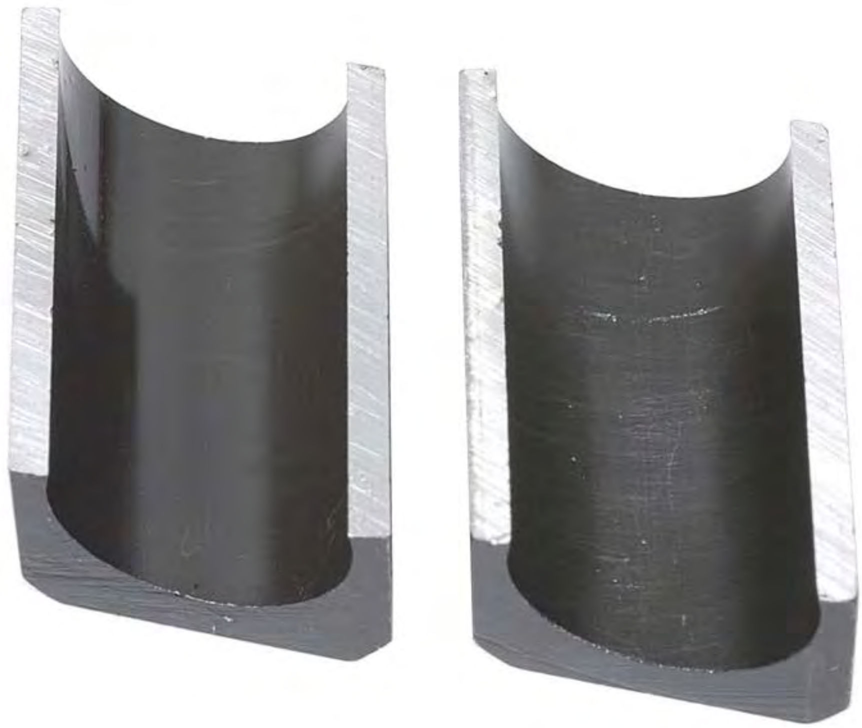


SN15396475 Transfer Pump Blades (Side), After

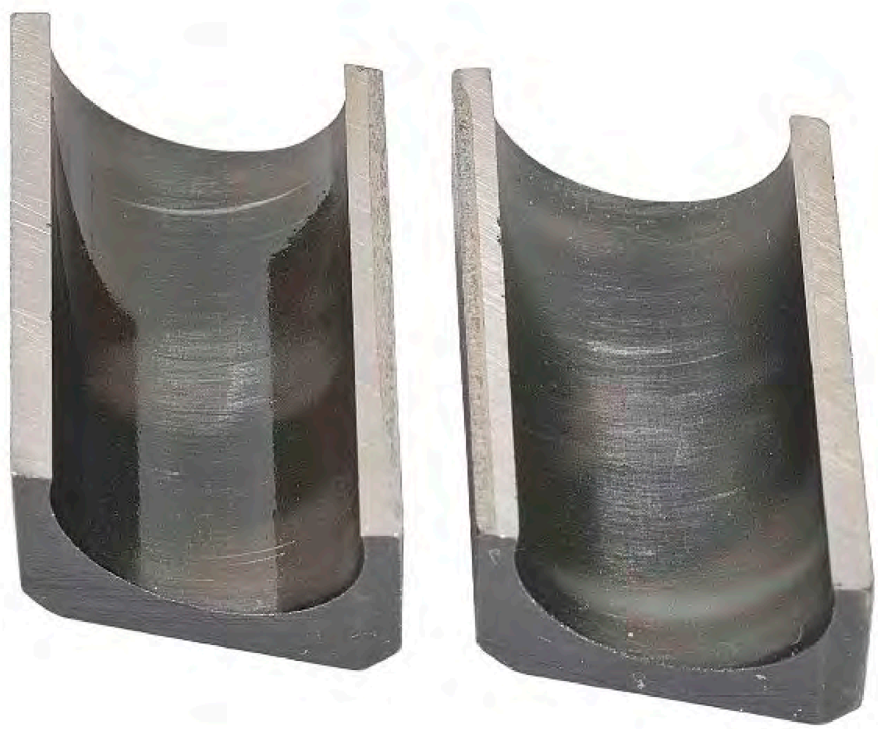
SN15396475 Transfer Pump Blades (Profile), Before



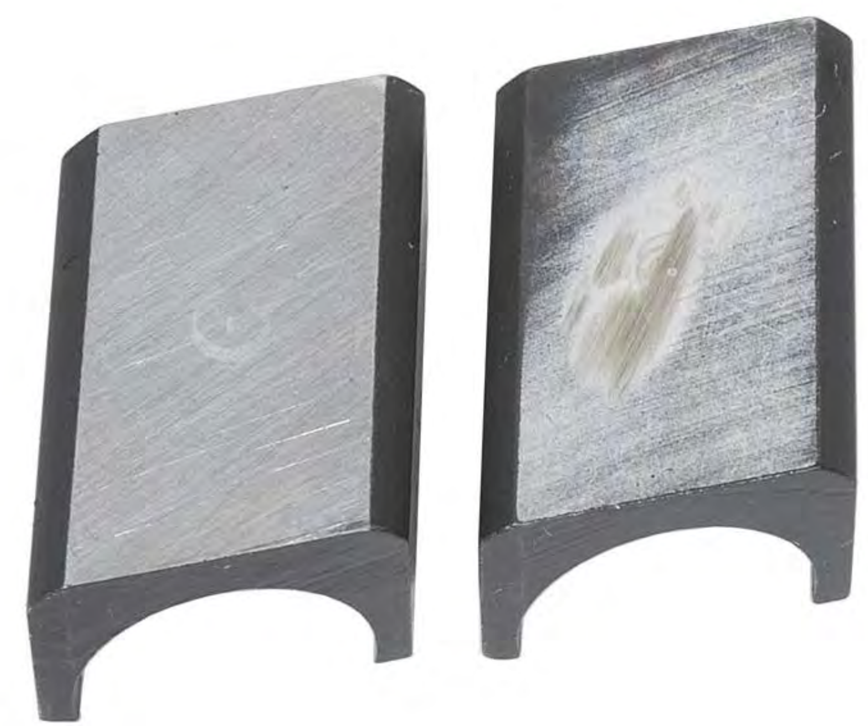
SN15396475 Transfer Pump Blades (Profile), After



SN15396475 Shoes (Front), Before



SN15396475 Shoes (Front), After



SN15396475 Shoes (Back), Before

SN15396475 Shoes (Back), After

SN15396475 Rollers, Before

SN15396475 Rollers, After

SN15396475 Piston Plungers, Before

SN15396475 Piston Plungers, After

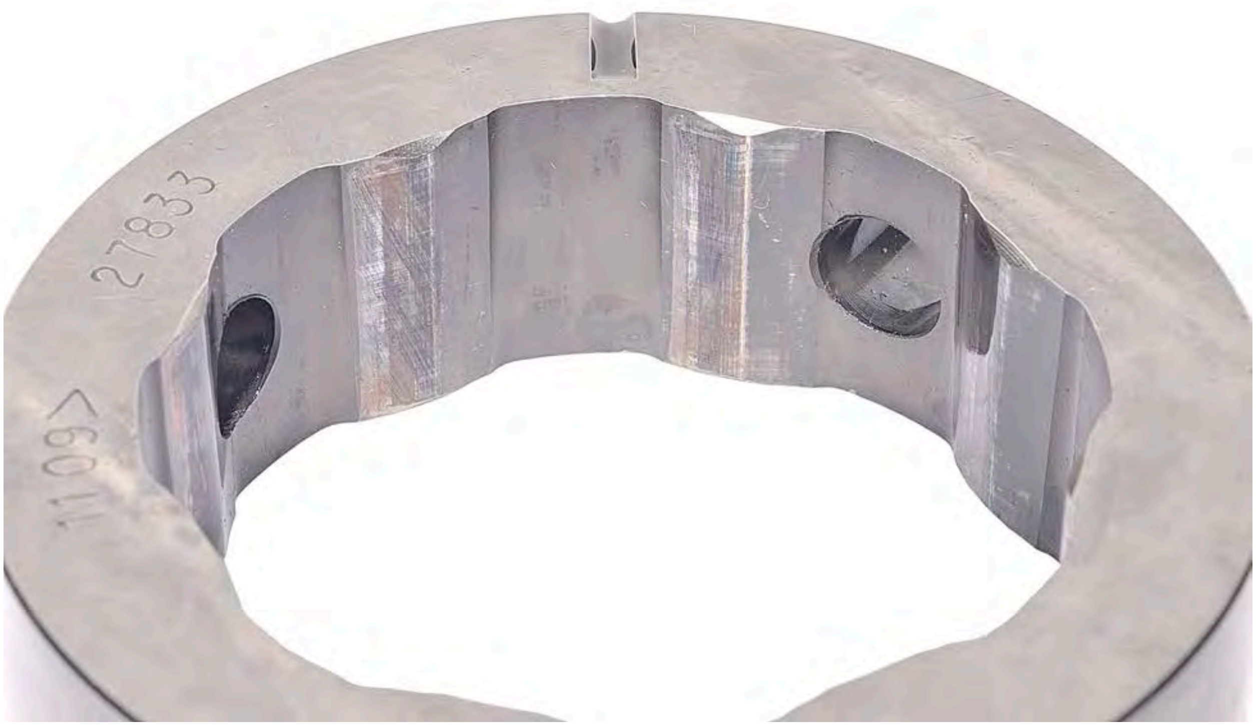
SN15396475 Thrust Washer, Before

SN15396475 Thrust Washer, After

SN15396475 Governor Weight, Before

SN15396475 Governor Weight, After

SN15396475 Cam Ring, Before



SN15396475 Cam Ring, After

SN15396475 Eccentric Ring, Before

SN15396475 Eccentric Ring, After

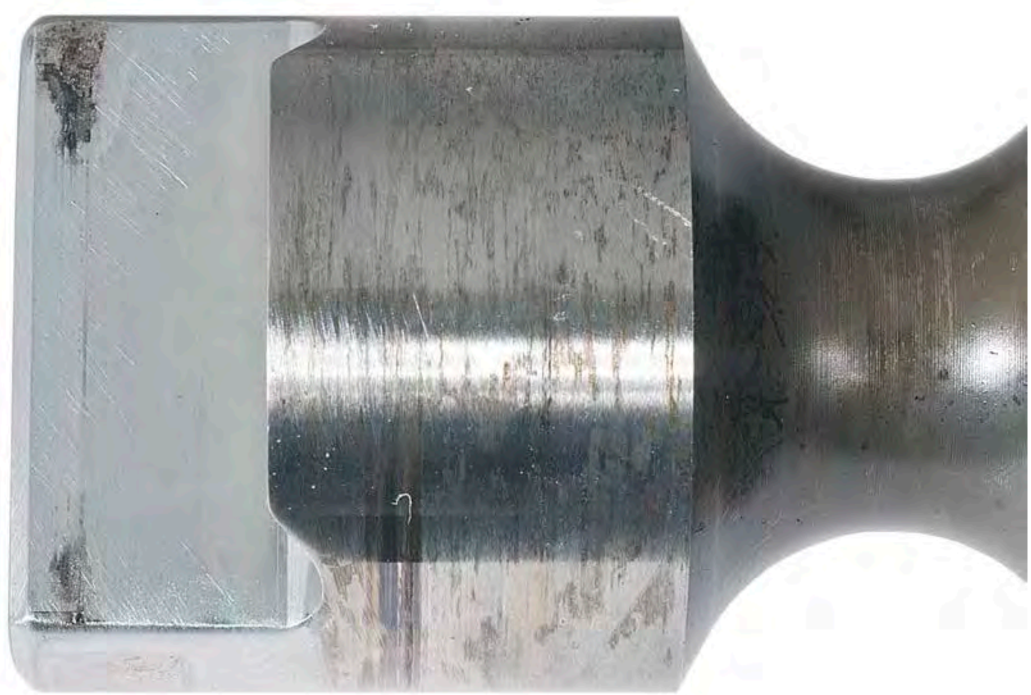
SN15396475 Rotor (Front), Before

SN15396475 Rotor (Front), After

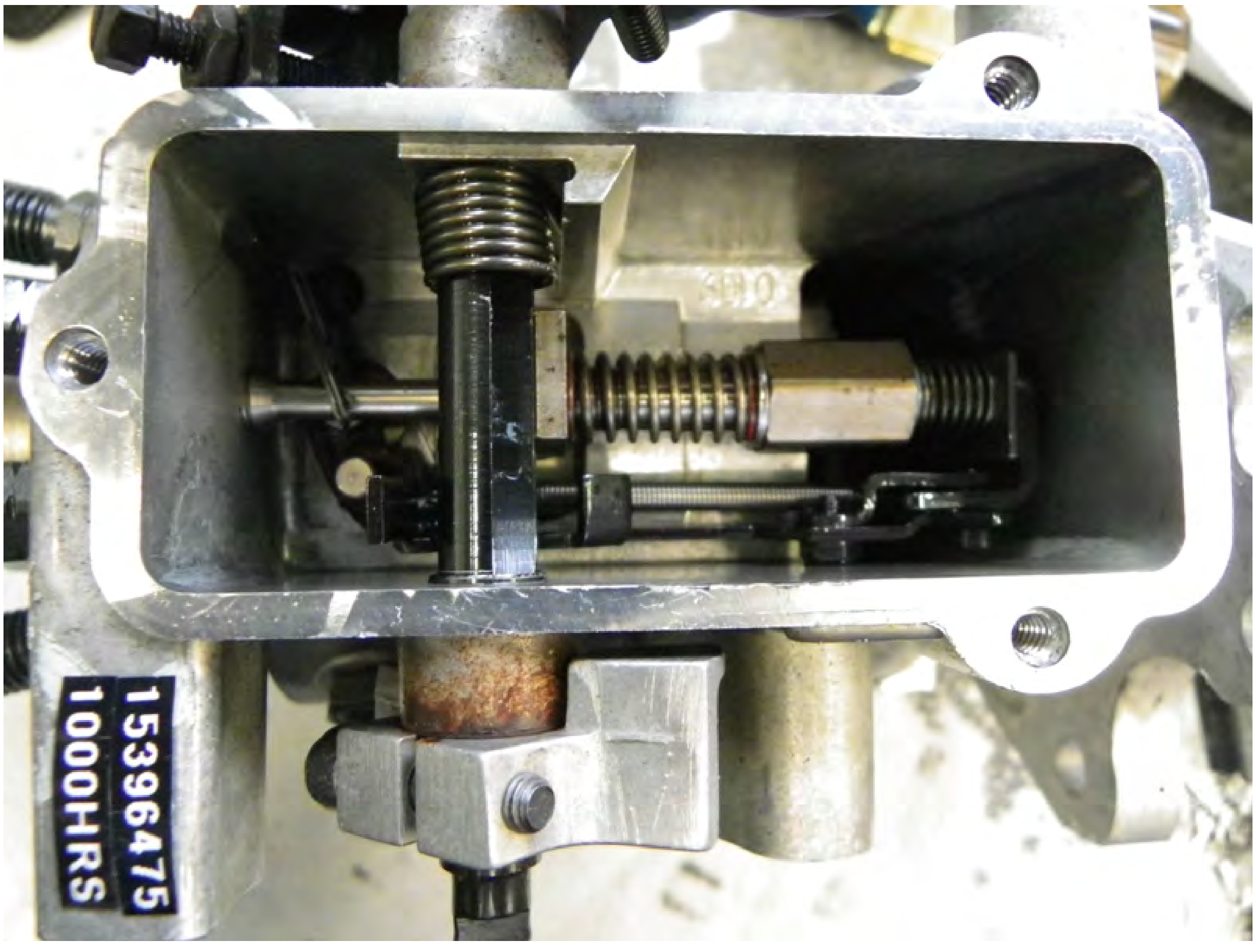
SN15396475 Rotor (Back), Before

SN15396475 Rotor (Back), After

SN15396475 Drive Tang, Before

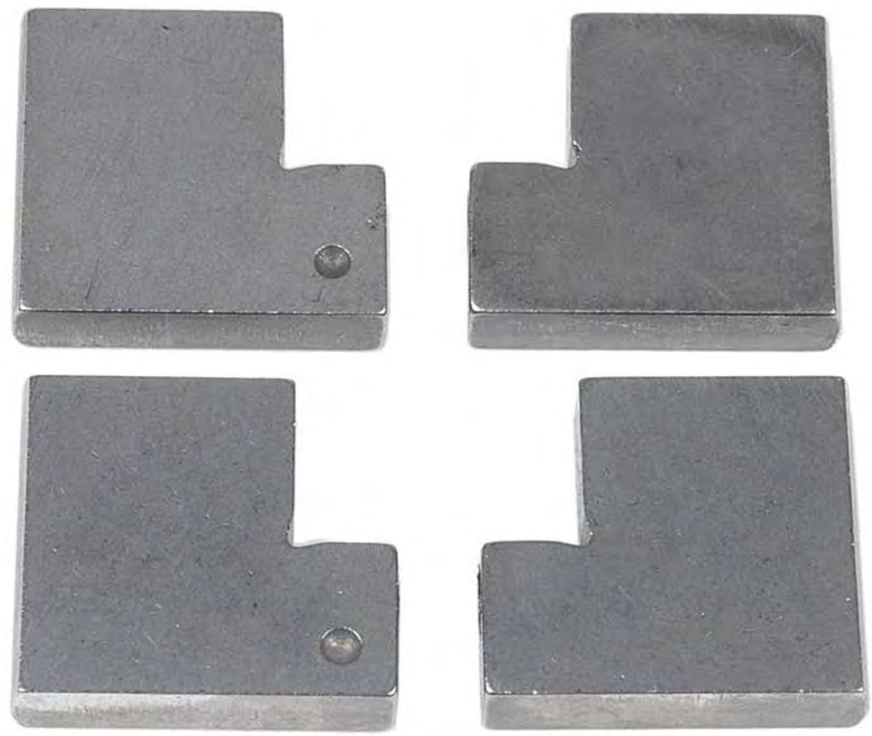


SN15396475 Drive Tang, After

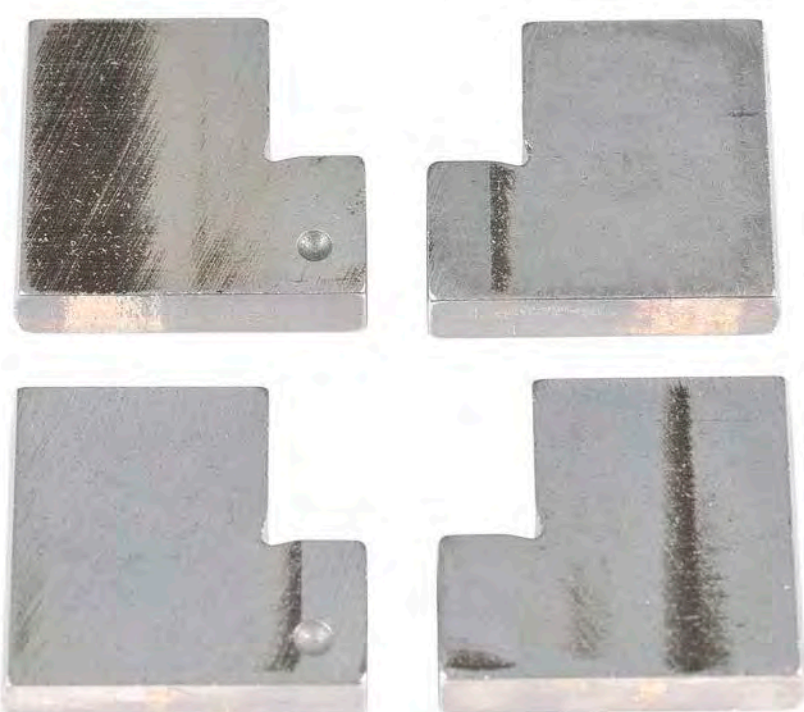


SN15396475 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



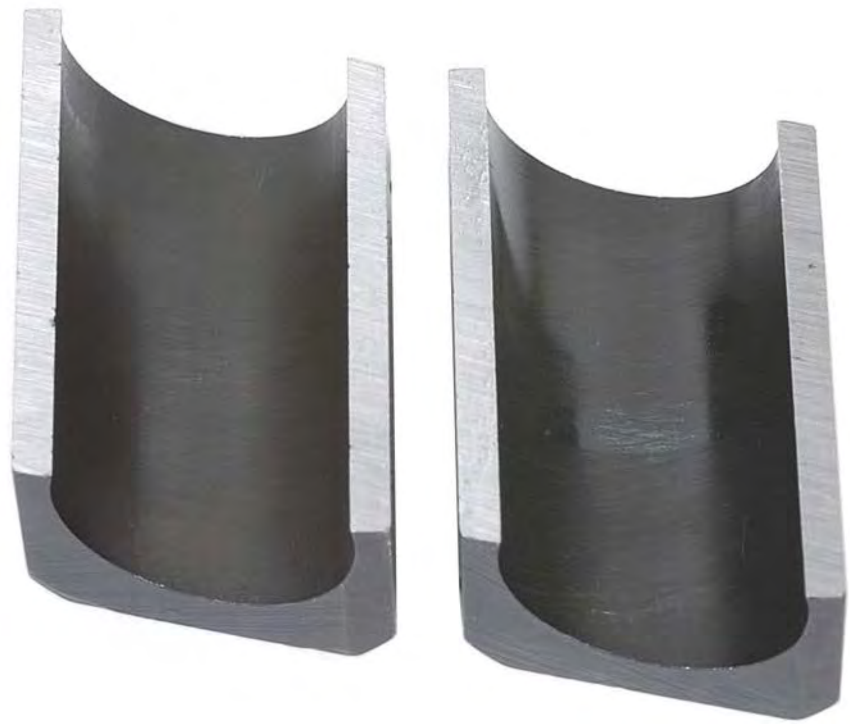
SN15396930 Transfer Pump Blades, Before



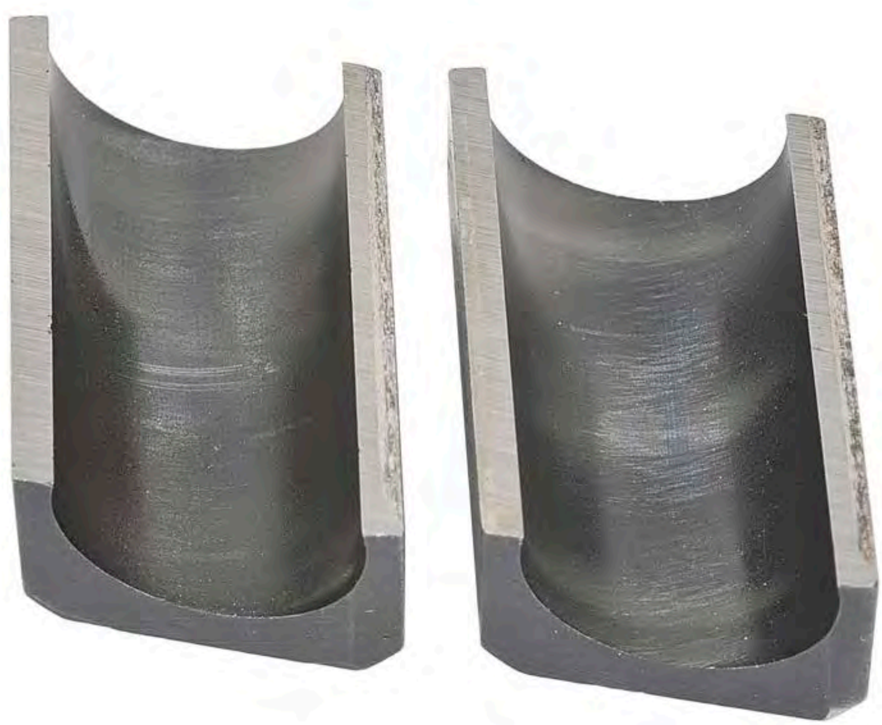
SN15396930 Transfer Pump Blades, After

SN15396930 Transfer Pump Blades (Profile), Before

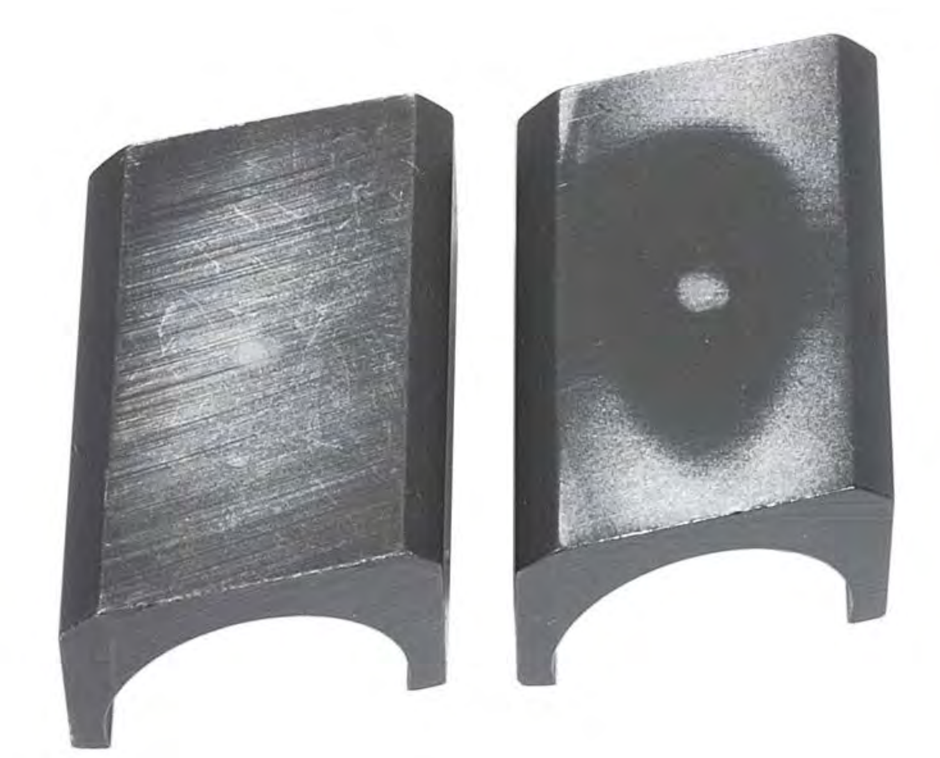
SN15396930 Transfer Pump Blades (Profile), After



SN15396930 Shoes (Front), Before



SN15396930 Shoes (Front), After



SN15396930 Shoes (Back), Before

SN15396930 Shoes (Back), After

SN15396930 Rollers, Before

SN15396930 Rollers, After

SN15396930 Piston Plungers, Before

SN15396930 Piston Plungers, After

SN15396930 Thrust Washer, Before

SN15396930 Thrust Washer, After

SN15396930 Governor Weight, Before

SN15396930 Governor Weight, After


SN15396930 Cam Ring, Before


SN15396930 Cam Ring, After

SN15396930 Eccentric Ring, Before

SN15396930 Eccentric Ring, After

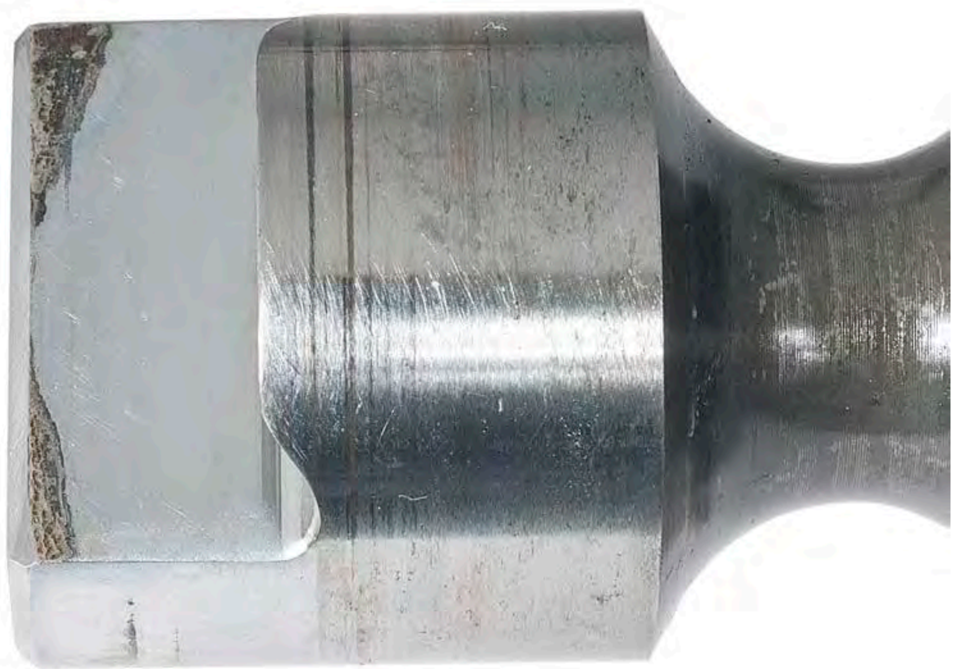
SN1596930 Rotor (Front), Before

SN1596930 Rotor (Front), After

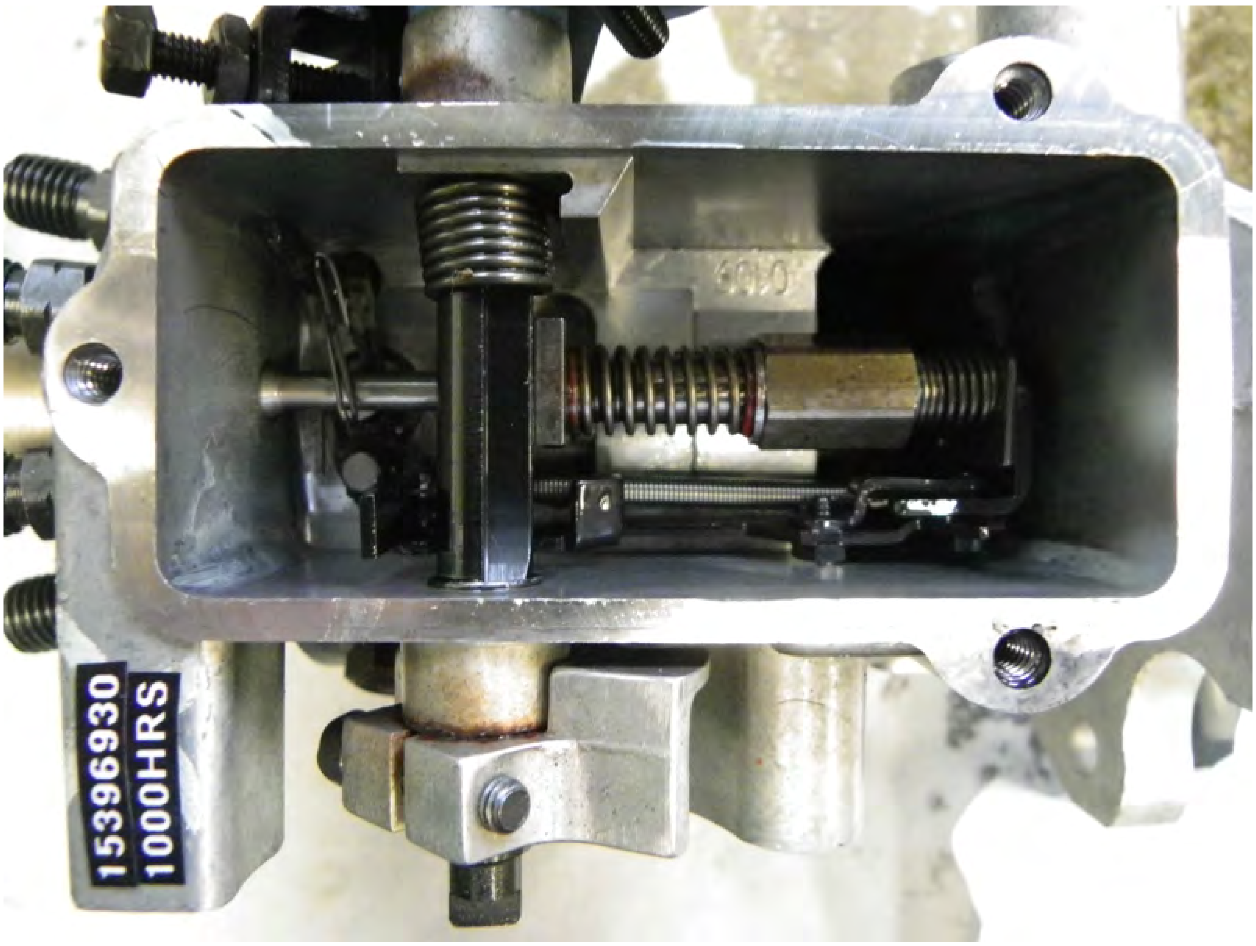
SN15396930 Rotor (Back), Before

SN15396930 Rotor (Back), After

SN15396930 Drive Tang, Before



SN15396930 Drive Tang, After



SN15396930 Governor Assembly

APPENDIX E

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 Turbine Fuel - No Additive
Test Number: C3T5-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 Turbine Fuel - No Additive
Test Fuel ID: AF 7090
Test Temperature: 40°C (104°F)
Test Number: C3T5-40-1000
Start of Test Date: January 11, 2011
End of Test Date: January 19, 2011
Test Duration: 124.5 Hrs

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure E-1.

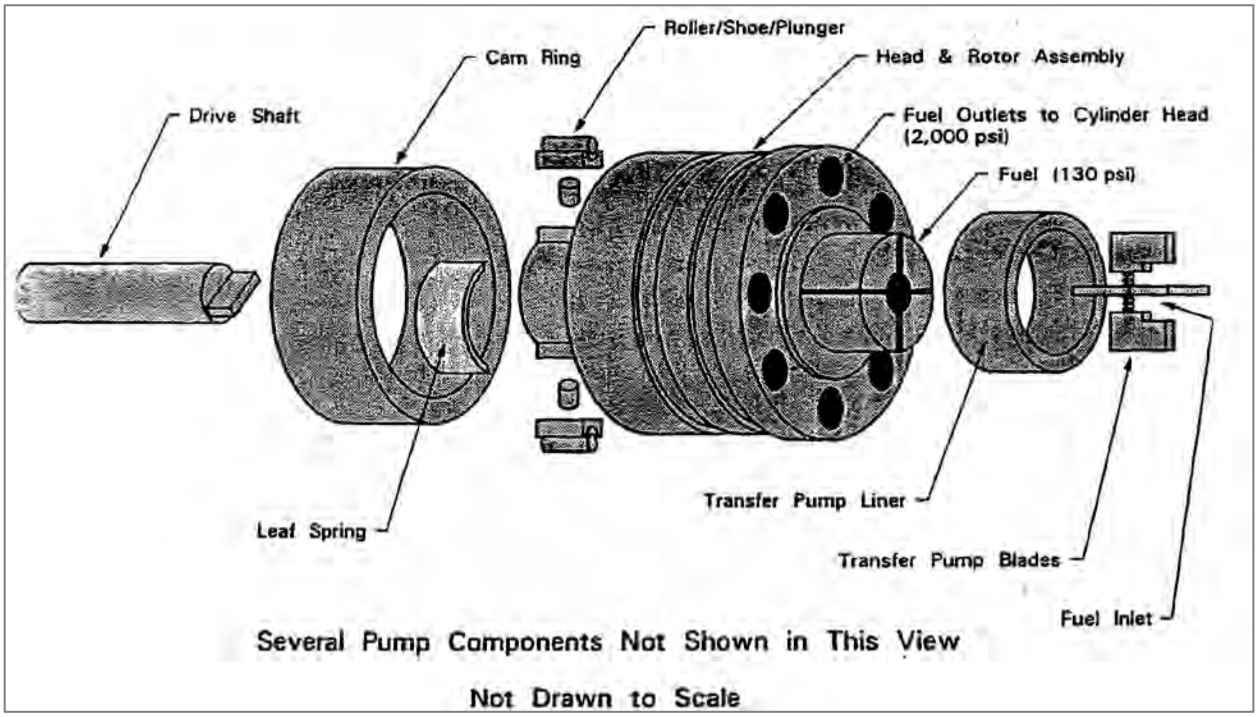


Figure E-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table E-1.

Table E-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table E-2.

Table E-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.40
FLO_R	Injected Flow Rate [mL/min]	936.3	88.57
FUELIN_P	Fuel Inlet Pressure [psig]	3.1	0.22
TRNS_P_R	Transfer Pump Pressure [psig]	79.60	.65
HSG_P_R	Pump Housing Pressure [psig]	10.55	.68
RTRN_T_R	Fuel Return Temperature [°C]	50.3	2.44
FUEL_T	Fuel Tank Temperature [°C]	26.4	6.34
FUELIN_T	Fuel Inlet Temperature [°C]	40.1	0.74

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure E-2 through Figure E-4.

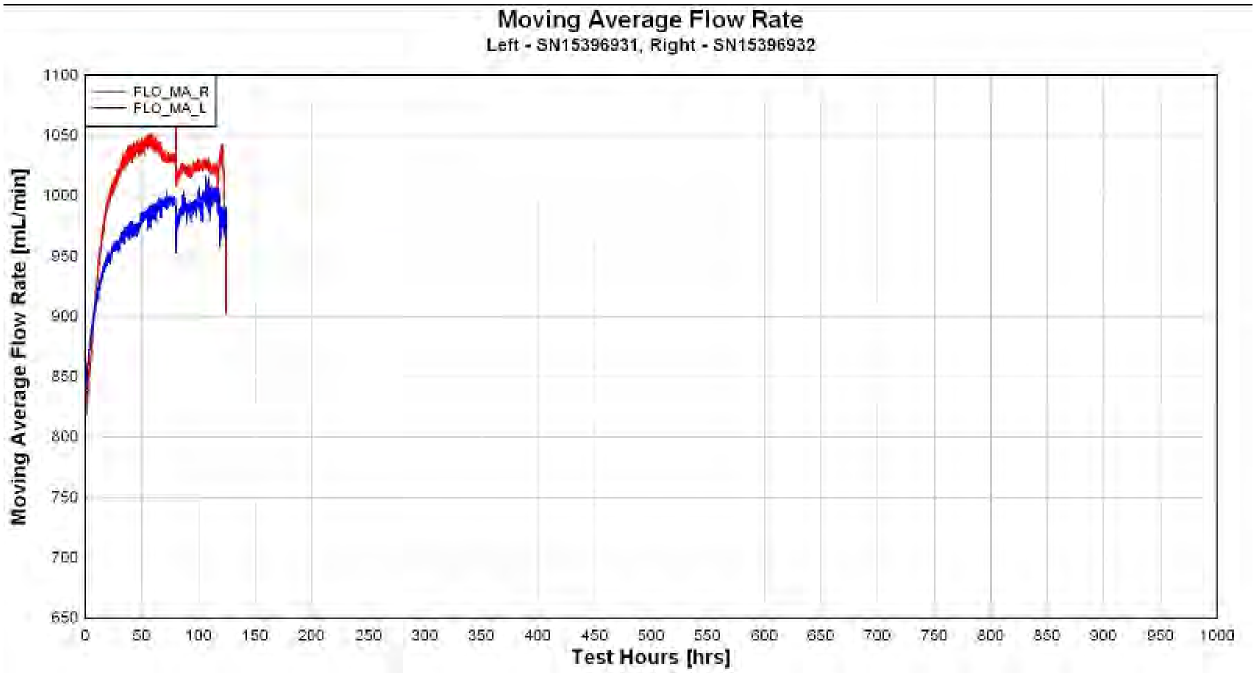


Figure E-2. Pump Flow, Moving Average

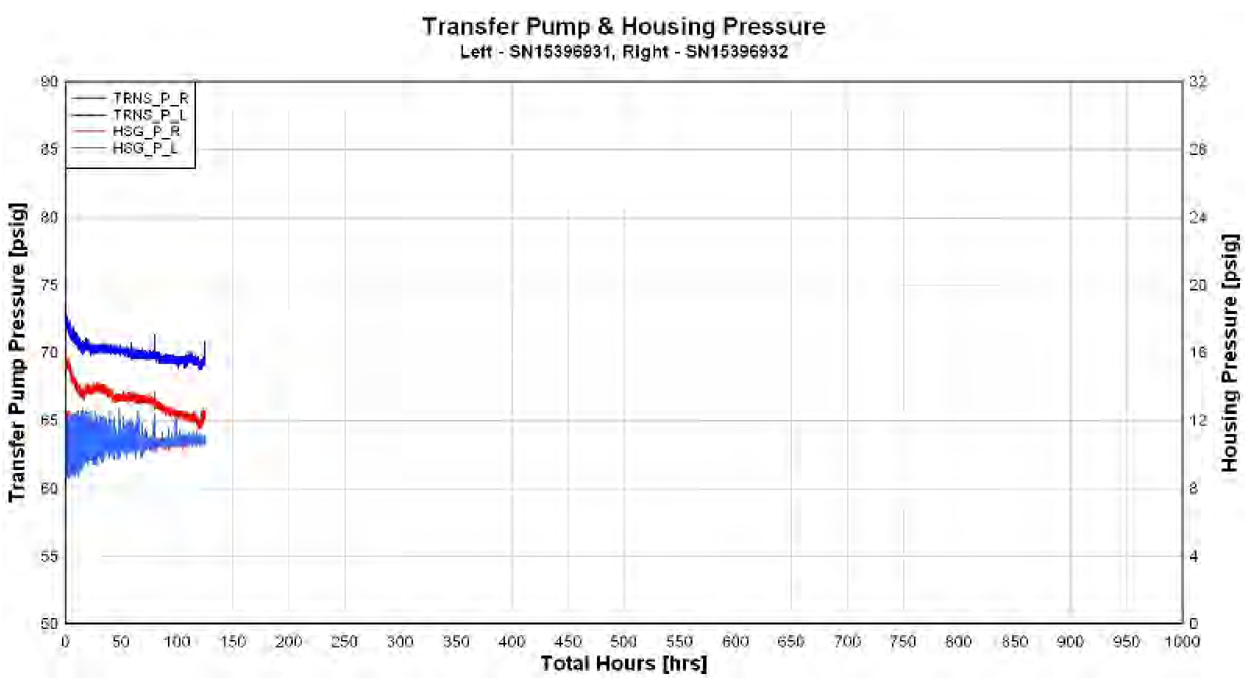


Figure E-3. Transfer Pump & Housing Pressure

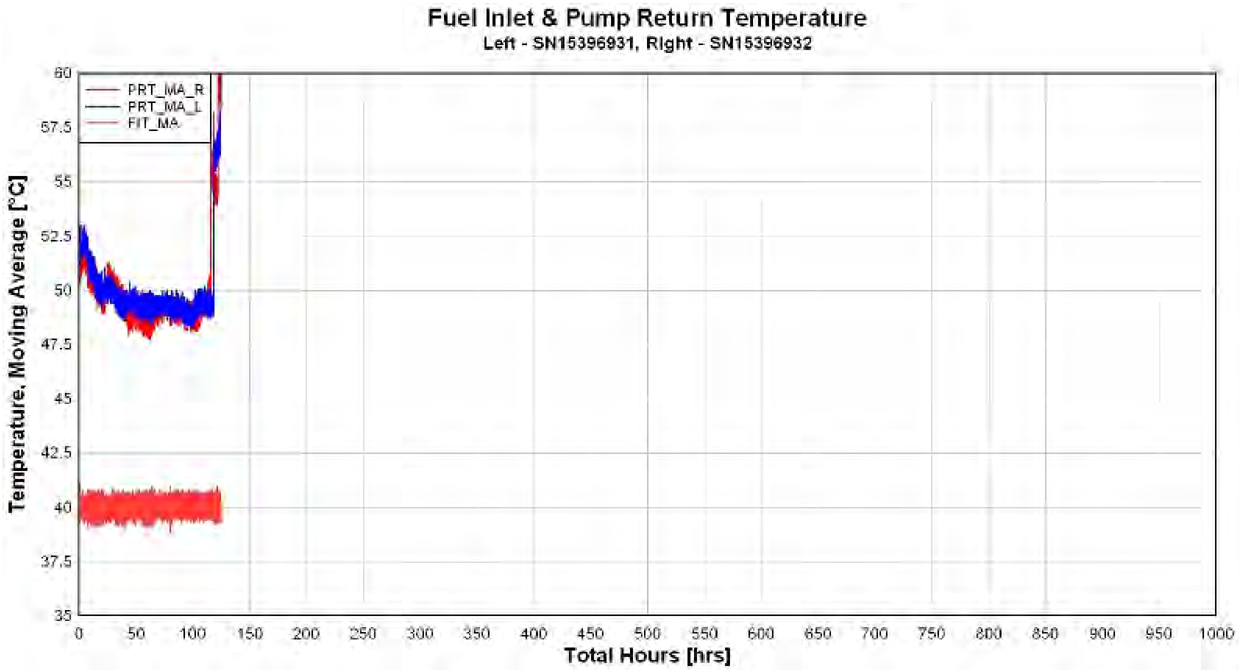


Figure E-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table E-3. (Note – Calibration data to be used as reference only)

Table E-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 5			Test Duration : 1000-hrs.		
Test Fuel :	Jet A-1 No Additive @ 105°F			SN : 15396931			SN : 15396932		
PUMP RPM	Description	Specification		Pump Duration : 124.5-hrs.			Pump Duration : 124.5-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	61 psi	60 psi	1 psi	62 psi	**ND**	
	Return Fuel	225 cc	375 cc	225 cc	265 cc	-40 cc	345 cc	**ND**	
350	Low Idle	12 cc	16 cc	14 cc	**5 cc**	9 cc	14 cc	**ND**	
	Housing psi.	8 psi	12 psi	9.0 psi	8.5 psi	.5 psi	9.0 psi	**ND**	
	Advance	3.50°		3.68°	**.00°**	3.68°	5.80°	ND	
	Cold Advance Solenoid	.0 psi	1.0 psi	1.0 psi	.5 psi	.5 psi	.0 psi	**ND**	
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	**ND**	
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	**89.0 cc**	-21.0 cc	68.0 cc	**ND**	
1600	WOT Fuel delivery	60 cc		67 cc	80 cc	-13 cc	64 cc	ND	
	WOT Advance	2.50°	3.50°	3.09°	.05°	3.04°	3.05°	ND	
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	**ND**	
	Face Cam Advance	5.25°	7.25°	6.15°	**4.86°**	1.29°	7.23°	**ND**	
	Low Idle	11.0°	12.0°	11.0°	**8.2°**	2.8°	11.0°	**ND**	
1825	Fuel Delivery	33 cc		39 cc	56 cc	-18 cc	39 cc	ND	
1950	High Idle		15 cc	1 cc	2 cc	-1 cc	2 cc	**ND**	
	Transfer pump psi.		125 psi	108 psi	109 psi	-1 psi	101 psi	**ND**	
200	WOT Fuel Delivery	58 cc		62 cc	85 cc	-23 cc	62 cc	ND	
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	**ND**	
75	Low Idle Fuel Delivery	37 cc		52 cc	70 cc	-18 cc	53 cc	ND	
	Transfer pump psi.	16 psi		29 psi	31 psi	-2 psi	24 psi	ND	
	Housing psi.	.0 psi	12 psi	6.0 psi	9 psi	-3 psi	7 psi	**ND**	
	Air Timing	-1.00°	.00°	-.50°	-1.00°	.50°	-.50°	**ND**	

Bold numbers = out of specification results

Notes : Pump stand stopped at 124.5 hours. Pump SN: 15396932 siezure at 124.5 hours.

No EOT Calibration

ND = Not Determined

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table E-4 and Table E-5.

Table E-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)	SN: 15396931	Test Number: 5
Fuel Description : Jet A-1 No Additive @ 105°F		

	Date:	7/28/2010	2/21/2011	
Transfer Pump Blade 1		***0-hrs.***	***125-hrs.***	***Change***
Measurement 1	Mass (g)	3.2744	3.2733	-0.0011
Measurement 2		3.2745	3.2731	-0.0014
Measurement 3		3.2744	3.2731	-0.0013
Measurement 4		3.2743	3.2731	-0.0012
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2495	3.2491	-0.0004
Measurement 2		3.2497	3.2490	-0.0007
Measurement 3		3.2495	3.2489	-0.0006
Measurement 4		3.2496	3.2490	-0.0006
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2568	3.2557	-0.0011
Measurement 2		3.2568	3.2557	-0.0011
Measurement 3		3.2568	3.2557	-0.0011
Measurement 4		3.2568	3.2557	-0.0011
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2546	3.2537	-0.0009
Measurement 2		3.2547	3.2535	-0.0012
Measurement 3		3.2547	3.2534	-0.0013
Measurement 4		3.2547	3.2535	-0.0012
Average Measurements		***0-hrs.***	***125-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2744	3.2732	-0.0013
Transfer Pump Blade 2		3.2496	3.2490	-0.0006
Transfer Pump Blade 3		3.2568	3.2557	-0.0011
Transfer Pump Blade 4		3.2547	3.2535	-0.0011
	Roller to Roller (in)	1.9760	2.0030	0.0270
	Eccentricity (in.)	0.0060	0.0090	0.0030
	Drive Backlash (In)	0.0040	0.0000	-0.0040

Table E-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396932	Test Number: 5	
Fuel Description : Jet A-1 No Additive @ 105°F				
	Date:	7/28/2010	2/10/2011	
Transfer Pump Blade 1		***0-hrs.***	***124.5-hrs.***	***Change***
Measurement 1	Mass (g)	3.2526	3.2349	-0.0177
Measurement 2		3.2527	3.2351	-0.0176
Measurement 3		3.2527	3.2348	-0.0179
Measurement 4		3.2528	3.2348	-0.0180
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2597	3.2391	-0.0206
Measurement 2		3.2597	3.2392	-0.0205
Measurement 3		3.2596	3.2391	-0.0205
Measurement 4		3.2596	3.2392	-0.0204
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2520	3.2343	-0.0177
Measurement 2		3.2519	3.2341	-0.0178
Measurement 3		3.2520	3.2342	-0.0178
Measurement 4		3.2520	3.2341	-0.0179
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2473	3.2261	-0.0212
Measurement 2		3.2472	3.2261	-0.0211
Measurement 3		3.2471	3.2261	-0.0210
Measurement 4		3.2473	3.2260	-0.0213
Average Measurements		***0-hrs.***	***125-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2527	3.2349	-0.0178
Transfer Pump Blade 2		3.2597	3.2392	-0.0205
Transfer Pump Blade 3		3.2520	3.2342	-0.0178
Transfer Pump Blade 4		3.2472	3.2261	-0.0212
	Roller to Roller (in)	1.9760	ND	
	Eccentricity (in.)	0.0060	ND	
Pump Siezure	Drive Backlash (In)	0.0040	ND	

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table E-6.

Table E-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection												
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
5	15396931	Jet A-1 No Additive @ 105°F	5-1	2150	1900	Pass	Pass	Pass	Pass	Pass	Pass
			5-2	2100	1975	Pass	Pass	Pass	Pass	Pass	Pass
			5-3	2150	1900	Pass	Pass	Pass	Pass	Pass	Pass
			5-4	2150	1800	Pass	Pass	Pass	Pass	Pass	Pass
			5-5	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			5-6	2150	1925	Pass	Pass	Pass	Pass	Pass	Pass
			5-7	2125	1900	Pass	Pass	Pass	Pass	Pass	Pass
			5-8	2200	1875	Pass	Pass	Pass	Pass	Pass	Pass
5	15396932	Jet A-1 No Additive @ 105°F	5-11	2150	1975	Pass	Pass	Pass	Pass	Pass	Pass
			5-12	2100	1950	Pass	Pass	Pass	Pass	Pass	Pass
			5-13	2125	1990	Pass	Pass	Pass	Pass	Pass	Pass
			5-14	2150	1925	Pass	Pass	Pass	Pass	Pass	Pass
			5-15	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			5-16	2125	1950	Pass	Pass	Pass	Pass	Pass	Pass
			5-17	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			5-18	2100	1925	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments : ______________________________

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table E-7 and Table E-8.

Table E-7. Stanadyne Left Pump Parts Evaluation

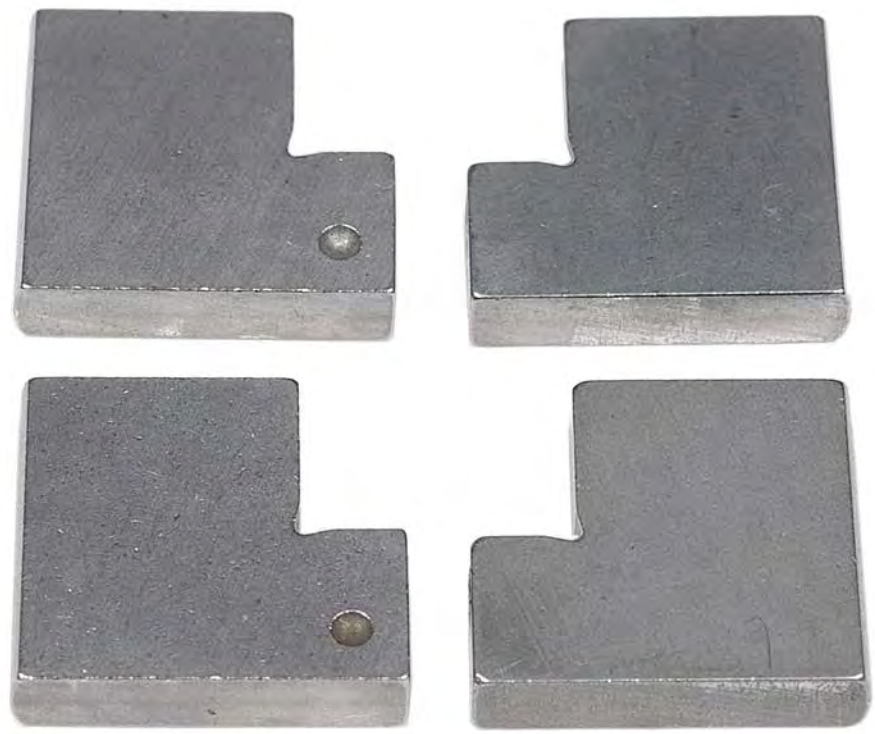
Pump Type DB2831-5079 (arctic):		SN: 15396931
Test Condition : Jet A-1 No Additive @ 105°F		Pump Duration : 124.5-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Polishing wear-rotor slots and liner contact	1
BLADE SPRINGS	Rubbing wear	3
LINER	Rubbing wear	1.5
TRANSFER PUMP REGULATOR	Polishing wear from rotor contact	1
REGULATOR PISTON	Light polishing wear	1
ROTOR	Normal	1
ROTOR RETAINERS	Wear marks from rotor contacts	1.5
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Polishing wear from shoe contact	2
SHOES	wear from rollers, plunger, and leaf spring	4.5
ROLLERS	Scarring and pitting wear	4.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Scarred on lobes from contact with rollers	4
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Polishing from linkage hook fingers	1
GOVORNER WEIGHTS	Light wear from T washer	1
LINK HOOK	Worn at pivot spot - polishing on fingers	2
METERING VAVLE	Polishing wear - stained brown	1.5
DRIVE SHAFT TANG	Some wear from rotor contact	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	0.002 inches out of round	3.5
ADVANCE PISTON	Fretting wear on top side	2.5
HOUSING	Bowl stained gold inside	1
	AVERAGE DEMERIT RATINGS	1.935

Table E-8. Stanadyne Right Pump Parts Evaluation

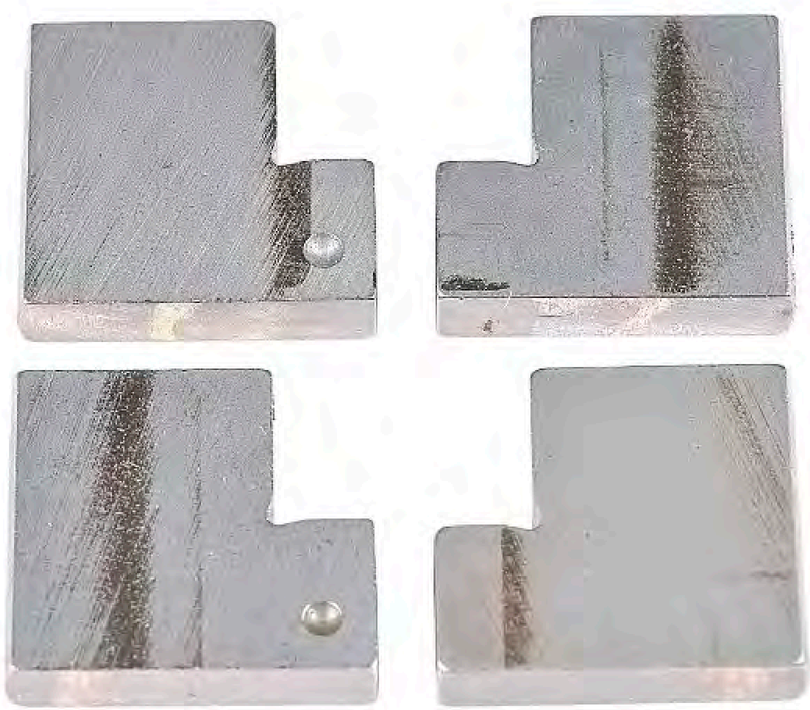
Pump Type : DB2831-5079 (arctic)	SN: 15396932
Test Condition : Jet A-1 No Additive @ 105°F	Pump Duration : 124.5-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Polishing wear-rotor slots and liner contact	1
BLADE SPRINGS	Rubbing wear	3
LINER	Rubbing wear	1
TRANSFER PUMP REGULATOR	Polishing wear from rotor contact	3
REGULATOR PISTON	Light polishing wear	1
ROTOR	Seized	5
ROTOR RETAINERS	Wear scars from rotor contacts	2.5
DELIVERY VALVE	Polishing wear	1.5
PLUNGERS	No scuffing but worn dimples at shoe contact	4
SHOES	Badly worn. Roller slot, plunger and leaf spring contact	5
ROLLERS	Diameter size is smaller from galling wear	5
LEAF SPRING	Deep grove worn into one side from shoe	4
CAM RING	Heavy wear and scarring on lobes	5
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Polishing from linkage hook fingers	1
GOVORNER WEIGHTS	Light wear from T washer	1
LINK HOOK	Worn at pivot spot - polishing on fingers	2
METERING VAVLE	Polishing wear - stained brown	1
DRIVE SHAFT TANG	Some wear from rotor contact	1.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	0.002 inches out of round	4
ADVANCE PISTON	Fretting wear on top side	3
HOUSING	Bowl stained gold inside	1
	AVERAGE DEMERIT RATINGS	2.500

PHOTOGRAPHS FOR LEFT PUMP



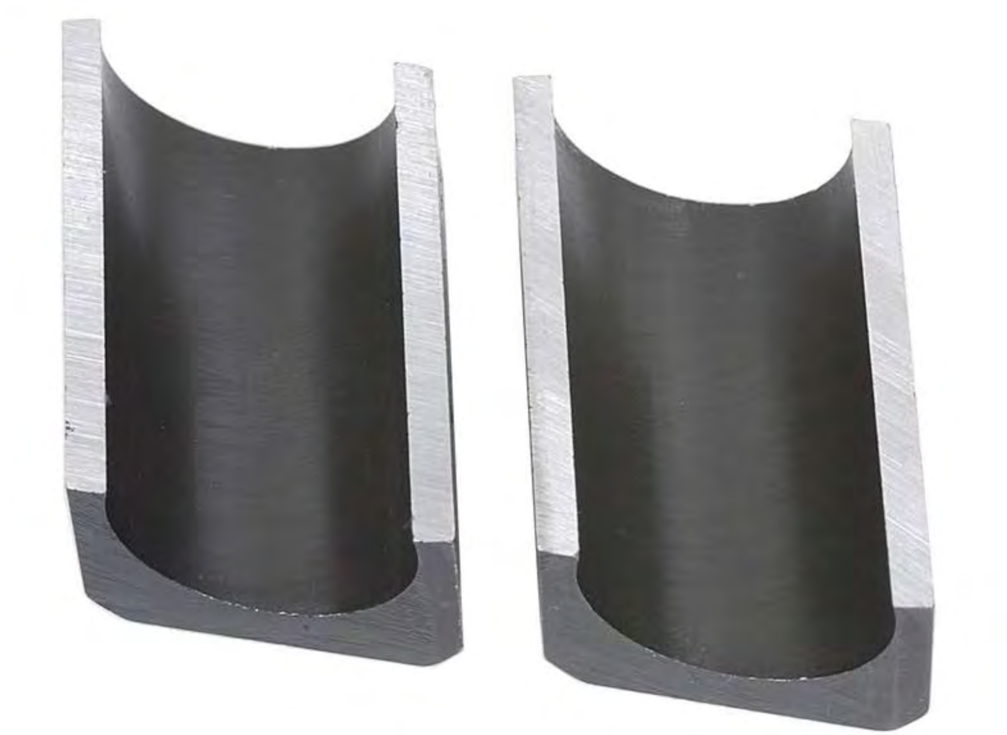
SN15396931 Transfer Pump Blades (Side), Before



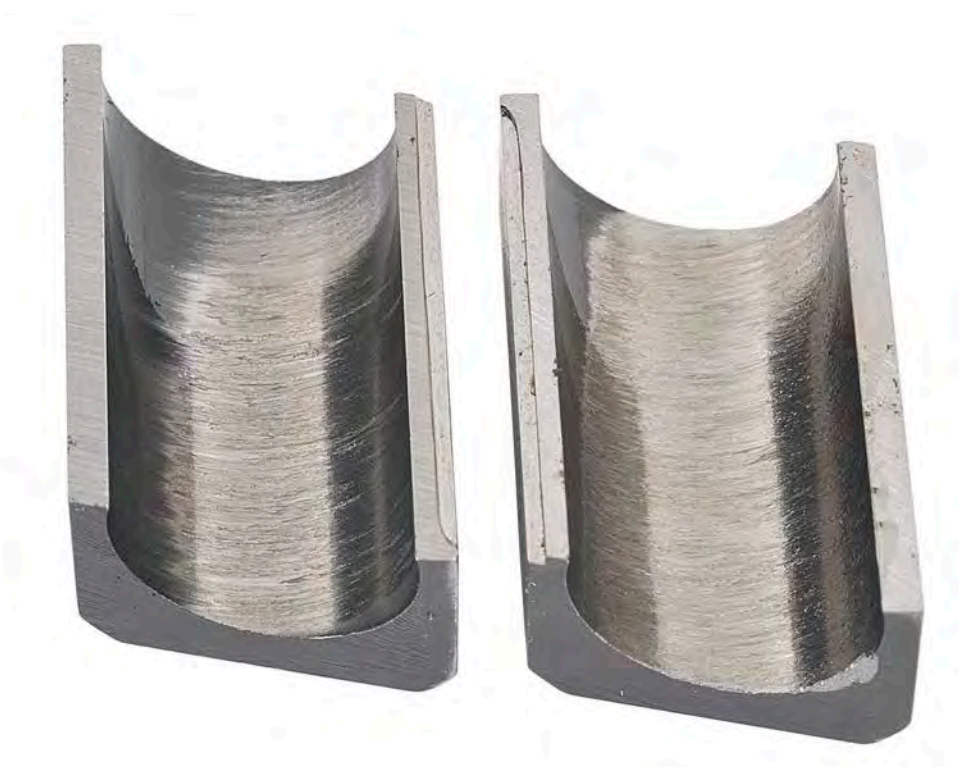
SN15396931 Transfer Pump Blades (Side), After

SN15396931 Transfer Pump Blades (Profile), Before

SN15396931 Transfer Pump Blades (Profile), After

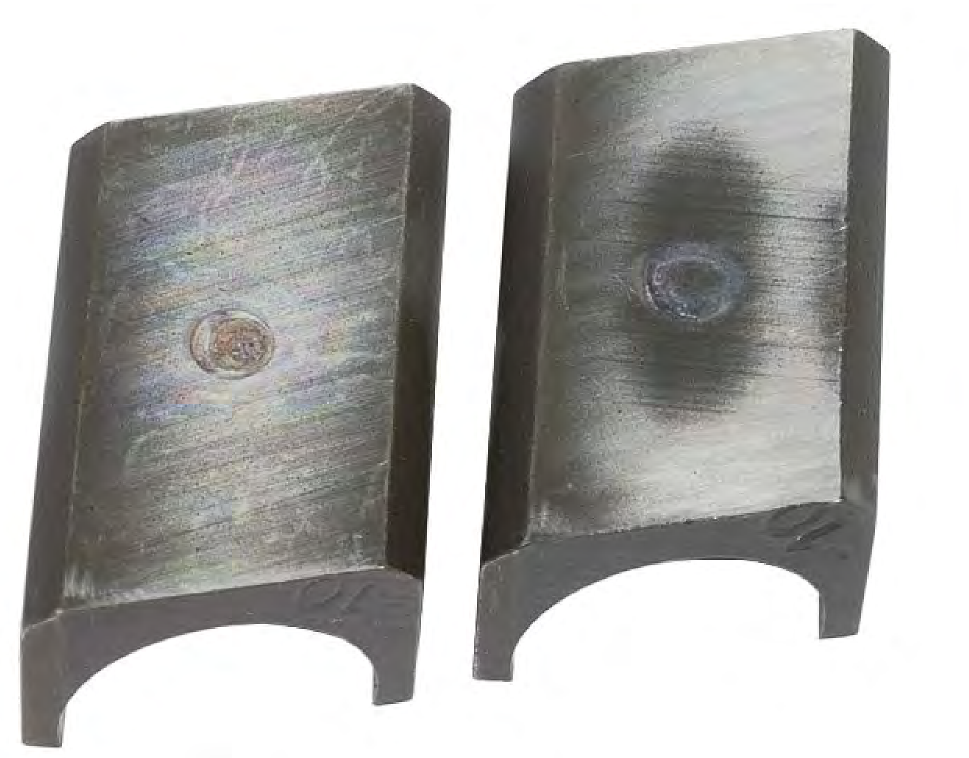


SN15396931 Shoes (Front), Before



SN15396931 Shoes (Front), After

SN15396931 Shoes (Back), Before



SN15396931 Shoes (Back), After

SN15396931 Rollers, Before

SN15396931 Rollers, After

SN15396931 Piston Plungers, Before

SN15396931 Piston Plungers, After

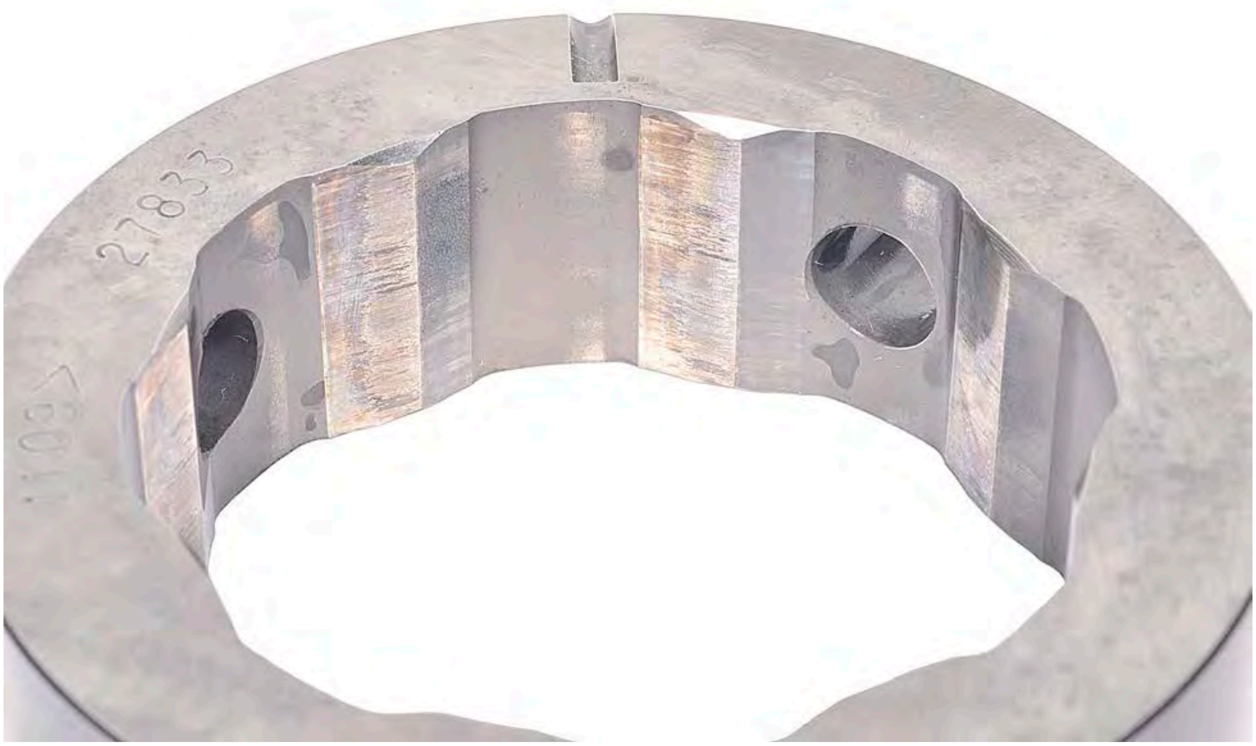
SN15396931 Thrust Washer, Before

SN15396931 Thrust Washer, After

SN15396931 Governor Weight, Before

SN15396931 Governor Weight, After

SN15396931 Cam Ring, Before



SN15396931 Cam Ring, After

SN15396931 Eccentric Ring, Before

SN15396931 Eccentric Ring, After

SN15396931 Rotor (Front), Before

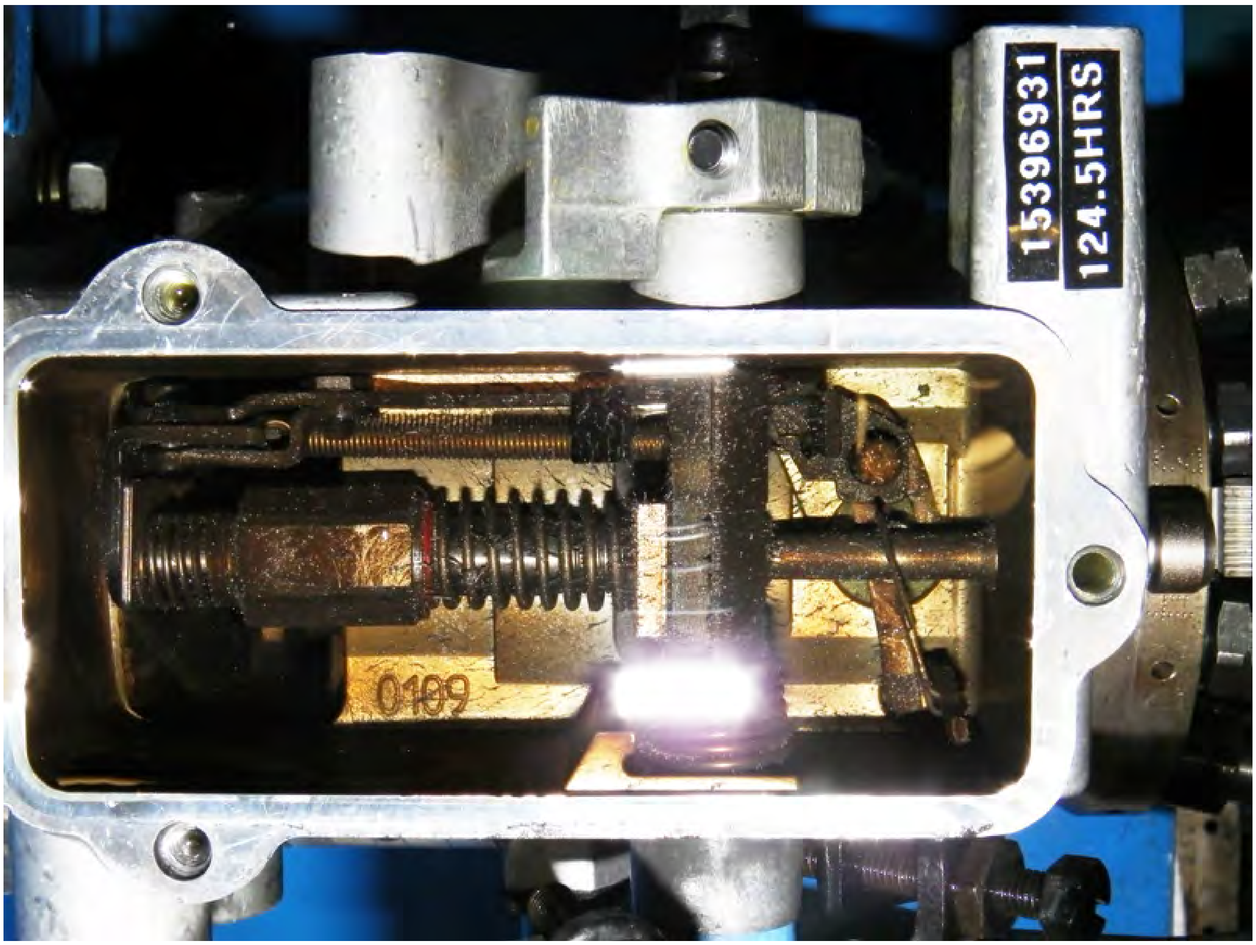
SN15396931 Rotor (Front), After

SN15396931 Rotor (Back), Before

SN15396931 Rotor (Back), After

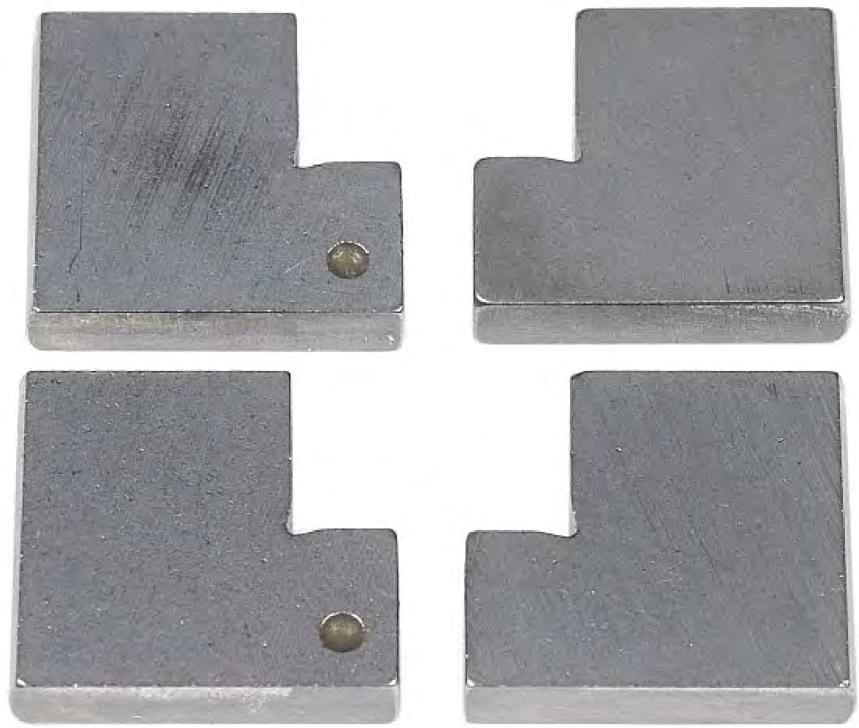
SN15396931 Drive Tang, Before

SN15396931 Drive Tang, After

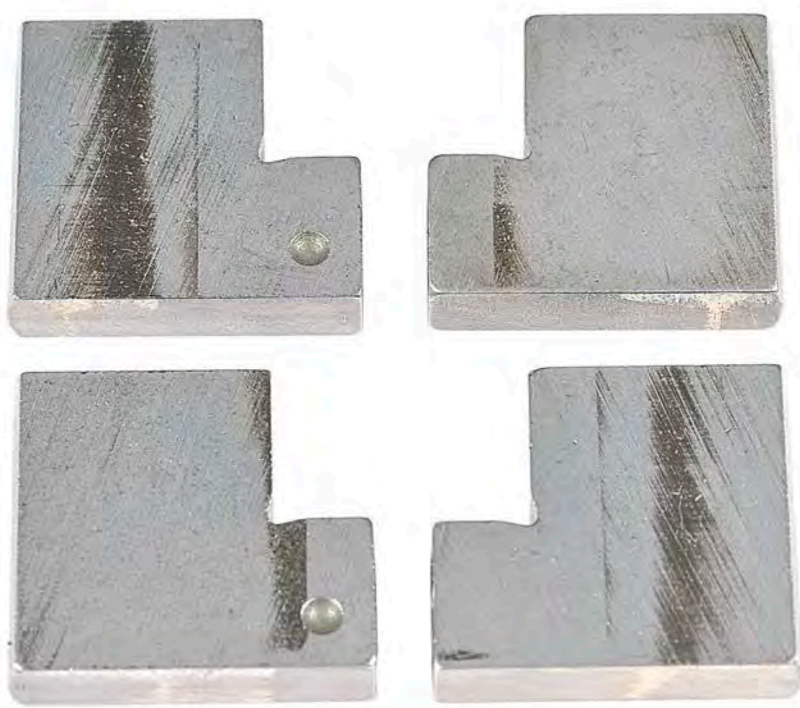


SN15396931 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



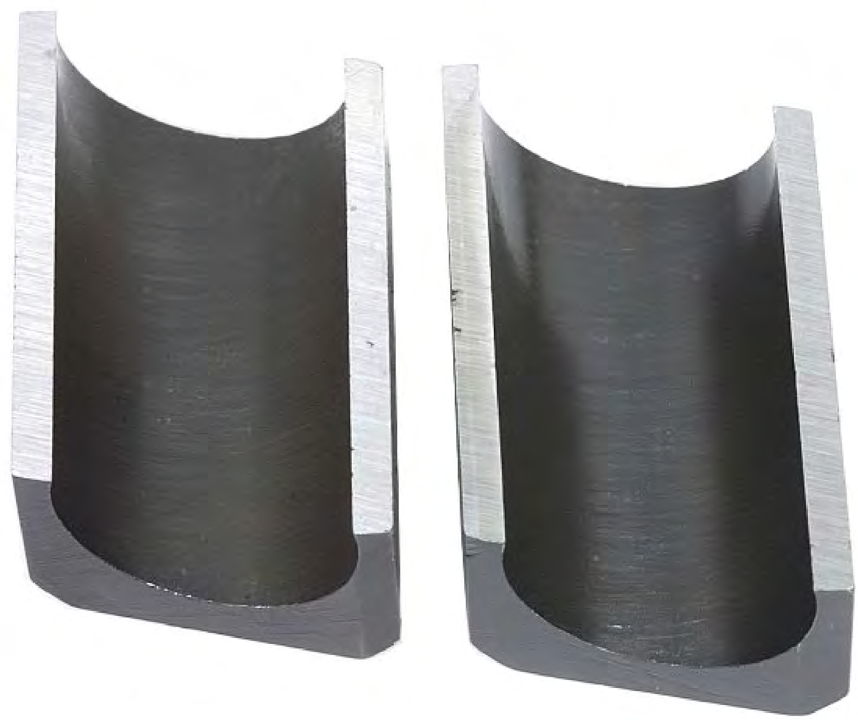
SN15396932 Transfer Pump Blades, Before



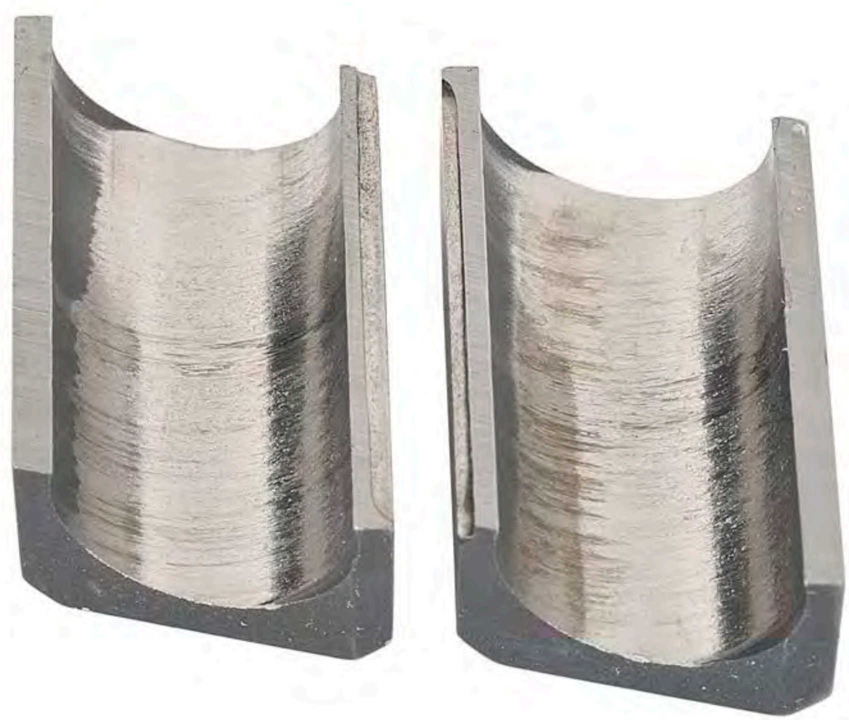
SN15396932 Transfer Pump Blades, Before

SN15396932 Transfer Pump Blades (Profile), Before

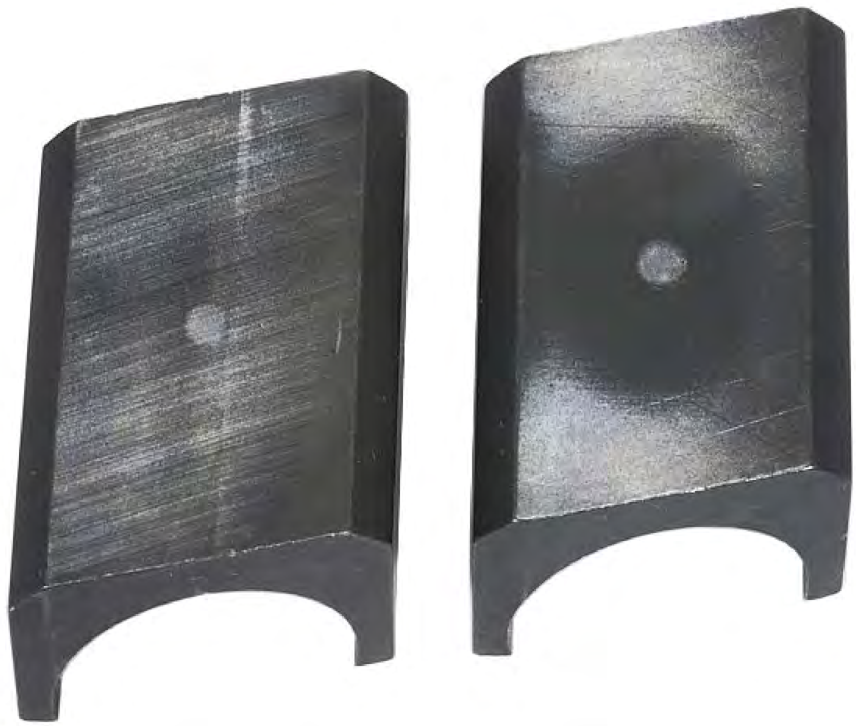
SN15396932 Transfer Pump Blades (Profile), After



SN15396932 Shoes (Front), Before



SN15396932 Shoes (Front), After



SN15396932 Shoes (Back), Before

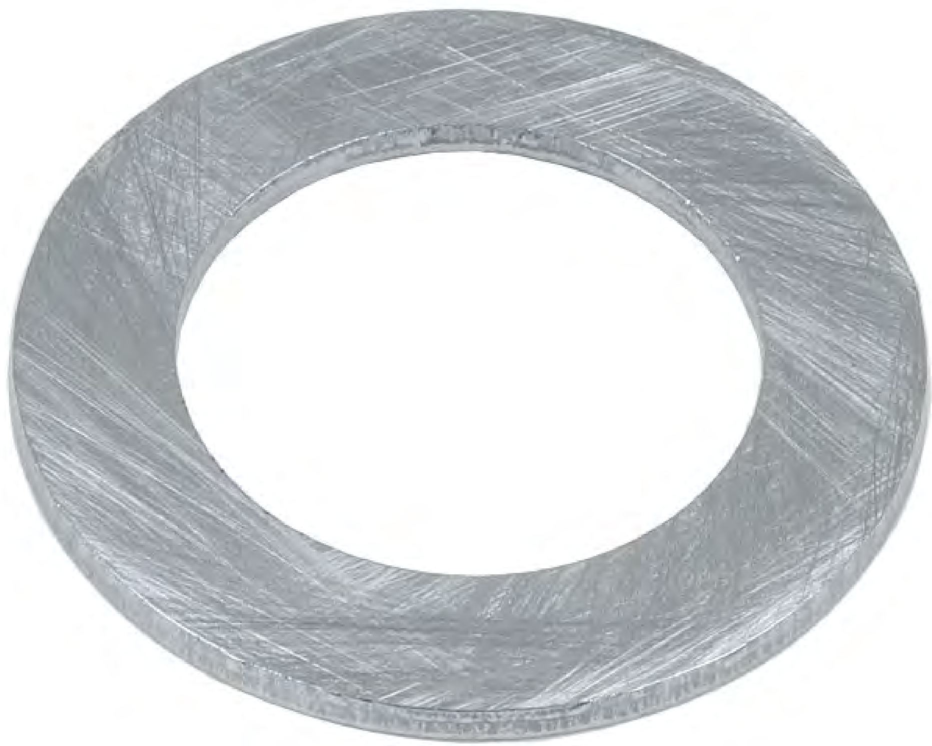
SN15396932 Shoes (Back), After

SN15396932 Rollers, Before

SN15396932 Rollers, After

SN15396932 Piston Plungers, Before

SN15396932 Piston Plungers, After

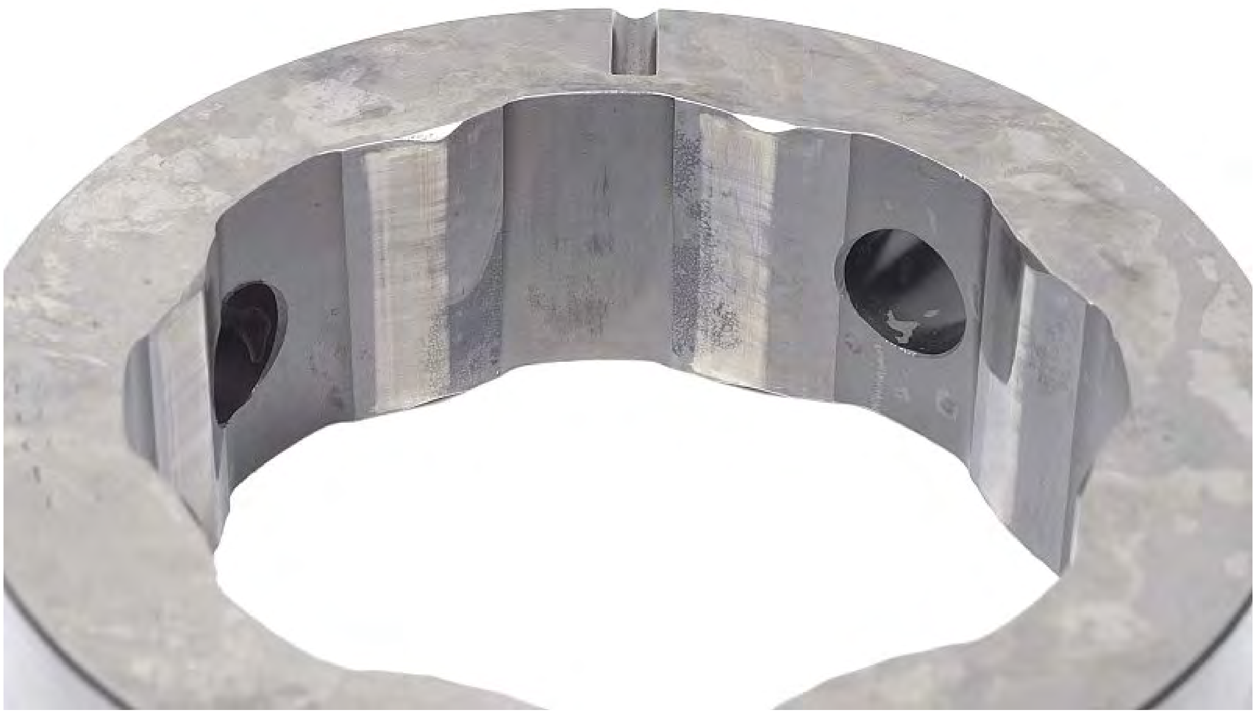


SN15396932 Thrust Washer, Before

SN15396932 Thrust Washer, After

SN15396932 Governor Weight, Before

SN15396932 Governor Weight, After



SN15396932 Cam Ring, Before

SN15396932 Cam Ring, After

SN15396932 Eccentric Ring, Before

SN15396932 Eccentric Ring, After

SN15396932 Rotor (Front), Before

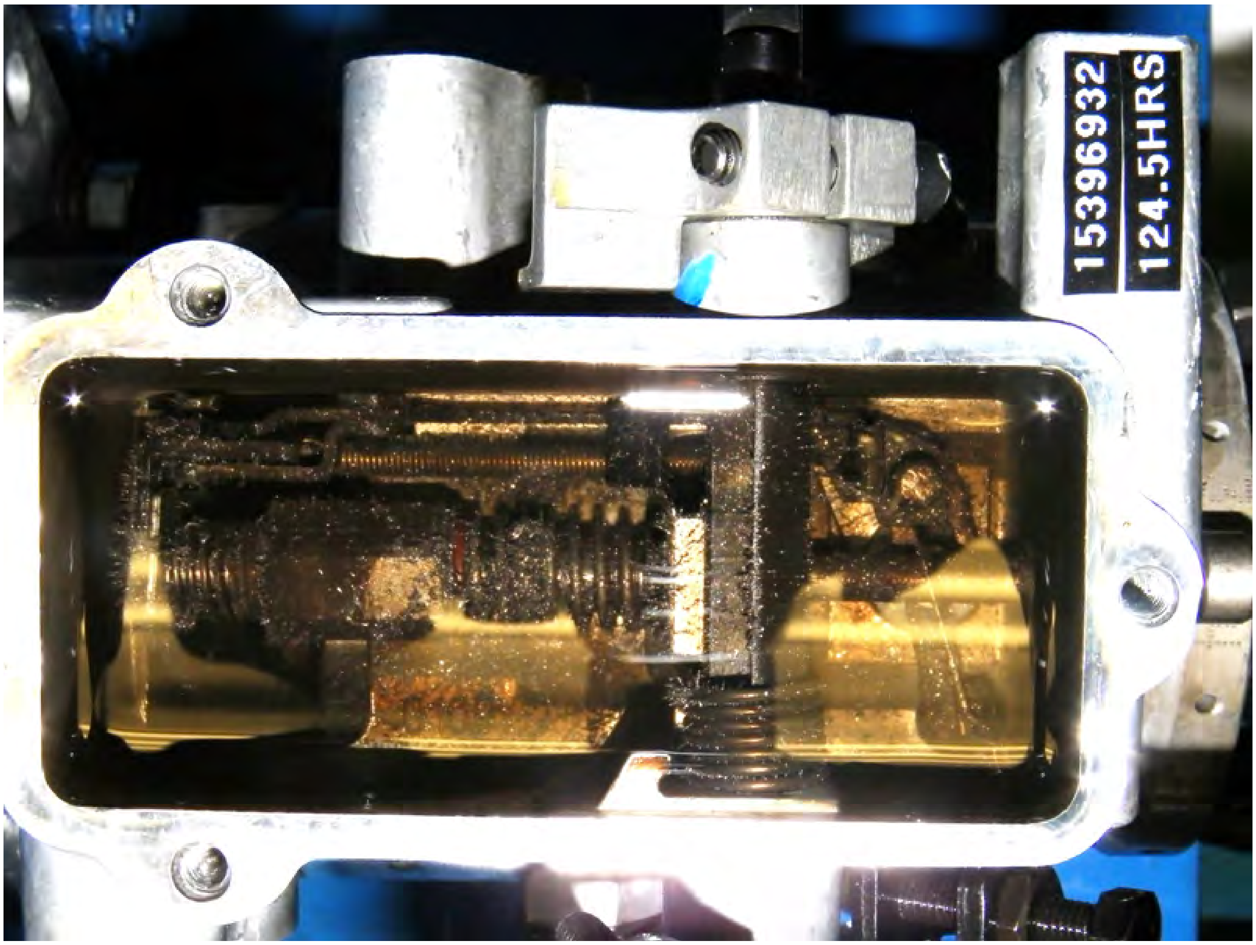
SN15396932 Rotor (Front), After

SN15396932 Rotor (Back), Before

SN15396932 Rotor (Back), Back

SN15396932Drive Tang, Before

SN15396932 Drive Tang, After



SN15396932 Governor Assembly

APPENDIX F

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 22.5-mg/L DCI-4A
Test Number: C3T6-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 22.5-mg/L DCI-4A

Test Fuel ID: AF7090

Test Temperature: 40°C (104°F)

Test Number: C3T6-40-1000

Start of Test Date: January 24, 2011

End of Test Date: March 28, 2011

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure F-1.

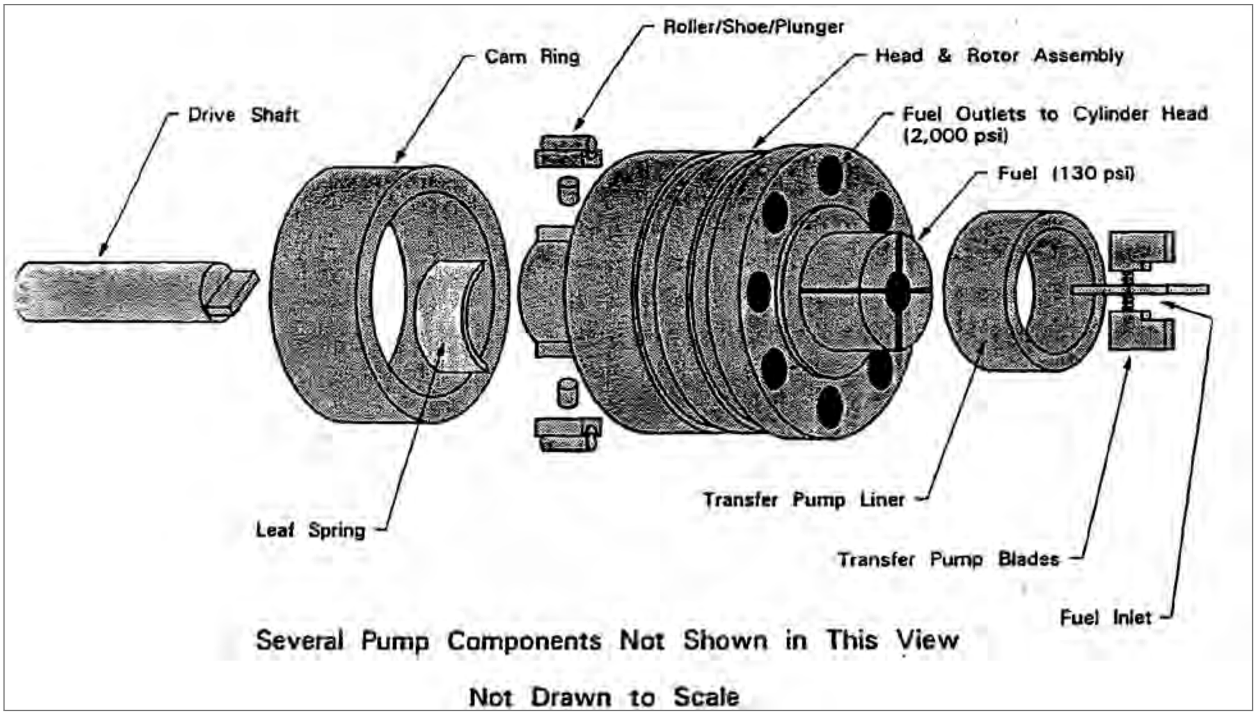


Figure F-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table F-1.

Table F-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table F-2.

Table F-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.25
FLO_R	Injected Flow-rate [mL/min]	805.30	12.36
FUELIN_P	Fuel Inlet Pressure [psig]	2.9	0.19
TRNS_P_R	Transfer Pump Pressure [psig]	71.1	0.44
HSG_P_R	Pump Housing Pressure [psig]	10.40	0.33
RTRN_T_R	Fuel Return Temperature [°C]	48.2	1.14
FUEL_T	Fuel Tank Temperature [°C]	28.5	4.35
FUELIN_T	Fuel Inlet Temperature [°C]	40.0	0.49

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure F-2 through Figure F-4.

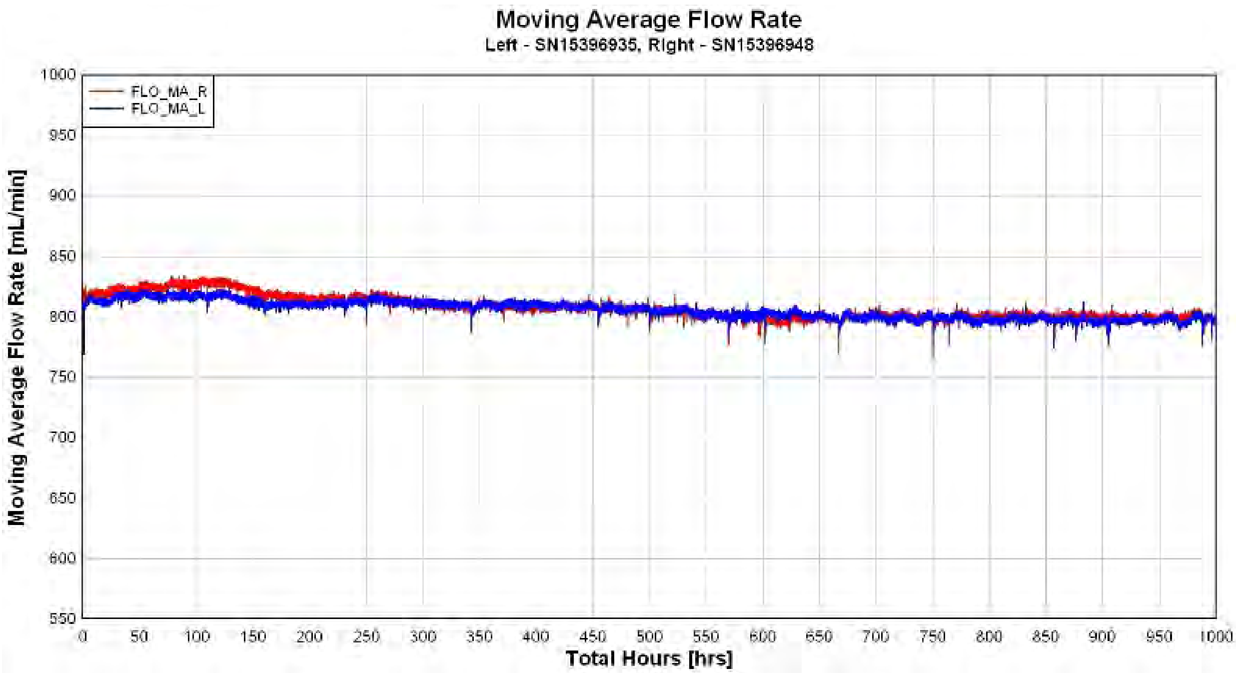


Figure F-2. Pump Flow, Moving Average

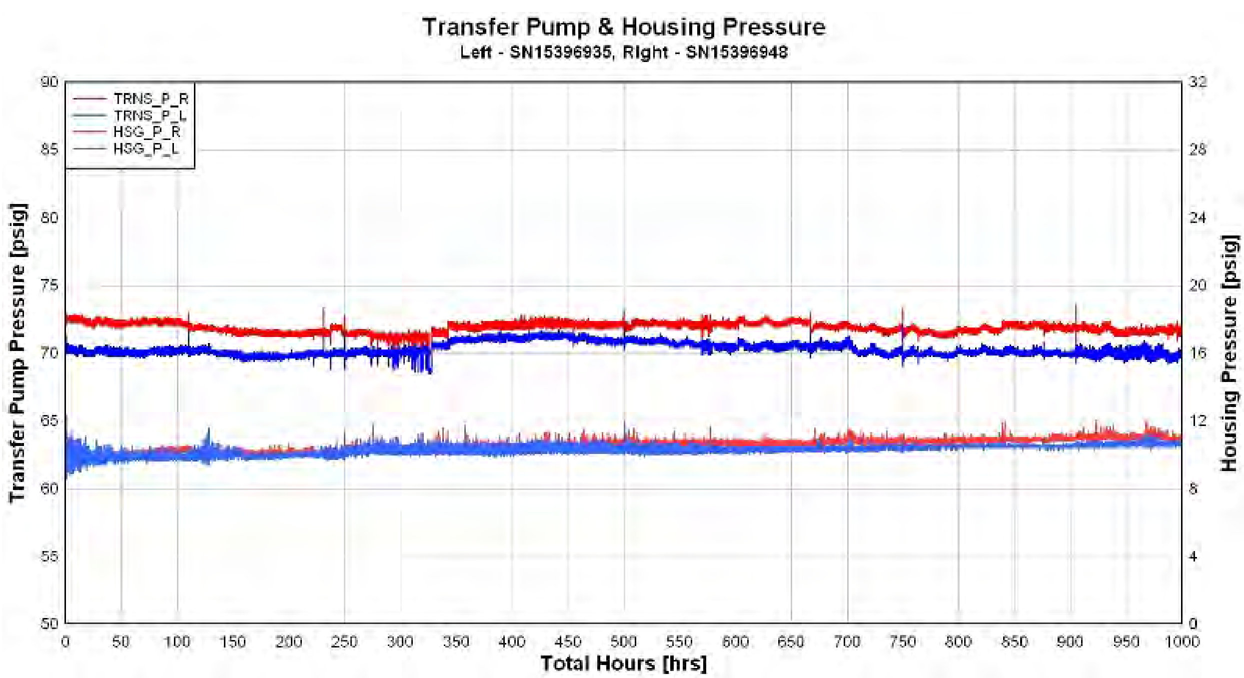


Figure F-3. Transfer Pump & Housing Pressure

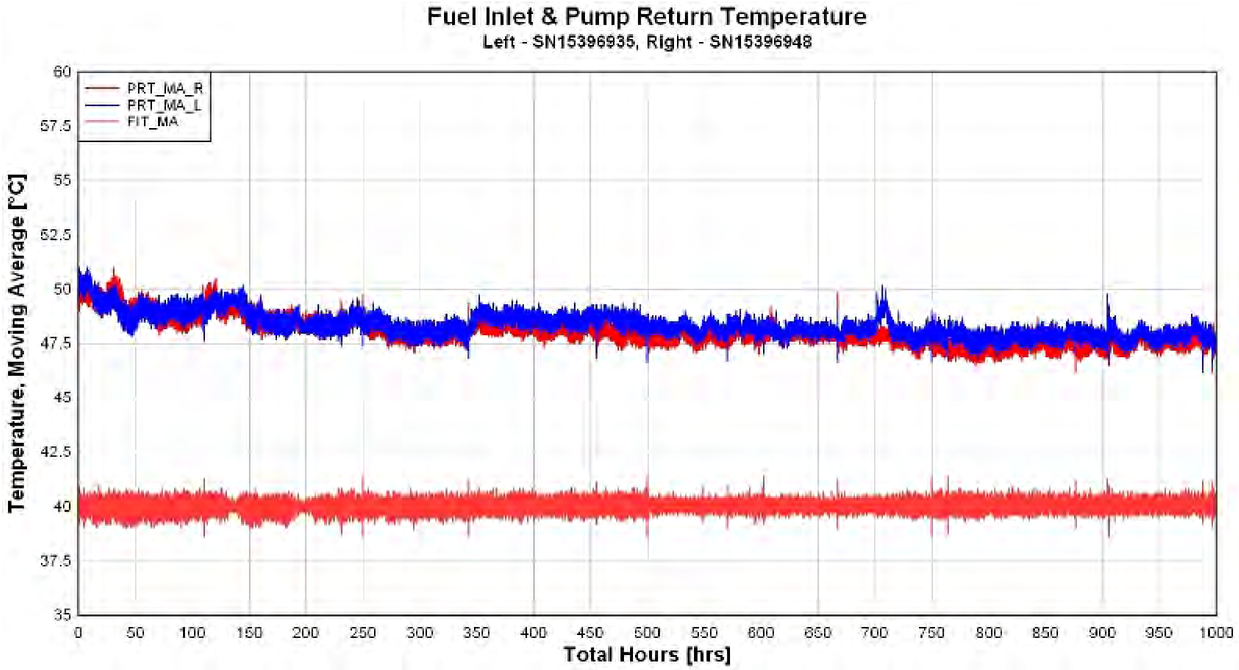


Figure F-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table F-3. (Note – Calibration data to be used as reference only).

Table F-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 6			Test Duration : 1000-hrs.		
Test Fuel : Jet A-1 with 22.5-mg/L DCI-4A @ 105°F				SN : 15396935			SN : 15396948		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	62 psi	psi	61 psi	**63 psi**	-2 psi
	Return Fuel	225 cc	375 cc	320 cc	350 cc	-30 cc	360 cc	372 cc	-12 cc
350	Low Idle	12 cc	16 cc	15 cc	**10 cc**	5 cc	15 cc	**8 cc**	7 cc
	Housing psi.	8 psi	12 psi	**4.7 psi**	9.0 psi	-4.4 psi	9.5 psi	10.0 psi	-.5 psi
	Advance	3.50°		4.65°	4.53°	.12°	4.20°	**3.20°**	1.00°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	**65.0 cc**	3.0 cc	68.0 cc	**65.0 cc**	3.0 cc
1600	WOT Fuel delivery	60 cc		66 cc	64 cc	2 cc	65 cc	62 cc	3 cc
	WOT Advance	2.50°	3.50°	2.99°	3.06°	-.07°	3.01°	2.80°	.21°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	23.0 cc	-1.0 cc
	Face Cam Advance	5.25°	7.25°	6.76°	6.30°	.46°	6.30°	5.48°	.82°
	Low Idle	11.0°	12.0°	11.3°	11.4°	.0°	11.2°	**10.9°**	.3°
1825	Fuel Delivery	33 cc		38 cc	58 cc	-20 cc	39 cc	48 cc	-9 cc
1950	High Idle		15 cc	1 cc	2 cc	-1 cc	2 cc	2 cc	cc
	Transfer pump psi.		125 psi	103 psi	105 psi	-2 psi	99 psi	107 psi	-8 psi
200	WOT Fuel Delivery	58 cc		62 cc	**56 cc**	6 cc	63 cc	60 cc	3 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		50 cc	44 cc	6 cc	54 cc	49 cc	5 cc
	Transfer pump psi.	16 psi		29 psi	**8 psi**	21 psi	25 psi	25 psi	0 psi
	Housing psi.	.0 psi	12 psi	8.0 psi	8 psi	1 psi	8 psi	9 psi	-1 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	.00°	-.50°	.50°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table F-4 and Table F-5.

Table F-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396935	Test Number: 6	
Fuel Description : Jet A-1 with 22.5-mg/L DCI-4A @ 105°F				
	Date:	8/5/2010	6/13/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2651	3.2617	-0.0034
Measurement 2		3.2653	3.2616	-0.0037
Measurement 3		3.2651	3.2616	-0.0035
Measurement 4		3.2651	3.2616	-0.0035
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2715	3.2676	-0.0039
Measurement 2		3.2715	3.2675	-0.0040
Measurement 3		3.2714	3.2675	-0.0039
Measurement 4		3.2714	3.2676	-0.0038
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2515	3.2471	-0.0044
Measurement 2		3.2513	3.2470	-0.0043
Measurement 3		3.2514	3.2470	-0.0044
Measurement 4		3.2514	3.2470	-0.0044
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2131	3.2081	-0.0050
Measurement 2		3.2127	3.2082	-0.0045
Measurement 3		3.2129	3.2081	-0.0048
Measurement 4		3.2128	3.2081	-0.0047
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2652	3.2616	-0.0035
Transfer Pump Blade 2		3.2715	3.2676	-0.0039
Transfer Pump Blade 3		3.2514	3.2470	-0.0044
Transfer Pump Blade 4		3.2129	3.2081	-0.0048
	Roller to Roller (in)	1.9760	1.9950	0.0190
	Eccentricity (in.)	0.0000	0.0000	0.0000
	Drive Backlash (In)	0.0000	0.0070	0.0070

Table F-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)	SN: 15396948	Test Number: 6
Fuel Description : Jet A-1 with 22.5-mg/L DCI-4A @ 105°F		

	Date:	8/9/2010	6/14/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2628	3.2601	-0.0027
Measurement 2		3.2629	3.2600	-0.0029
Measurement 3		3.2628	3.2600	-0.0028
Measurement 4		3.2627	3.2600	-0.0027
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2800	3.2767	-0.0033
Measurement 2		3.2802	3.2767	-0.0035
Measurement 3		3.2800	3.2767	-0.0033
Measurement 4		3.2801	3.2767	-0.0034
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2613	3.2584	-0.0029
Measurement 2		3.2612	3.2584	-0.0028
Measurement 3		3.2610	3.2582	-0.0028
Measurement 4		3.2610	3.2583	-0.0027
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2616	3.2478	-0.0138
Measurement 2		3.2616	3.2477	-0.0139
Measurement 3		3.2614	3.2477	-0.0137
Measurement 4		3.2614	3.2477	-0.0137
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2628	3.2600	-0.0028
Transfer Pump Blade 2		3.2801	3.2767	-0.0034
Transfer Pump Blade 3		3.2611	3.2583	-0.0028
Transfer Pump Blade 4		3.2615	3.2477	-0.0138
	Roller to Roller (in)	1.9760	1.9752	-0.0008
	Eccentricity (in.)	0.0090	0.0110	0.0020
	Drive Backlash (In)	0.0040	0.0080	0.0040

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table F-6.

Table F-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation

6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
6	15396935	Jet A-1 with 22.5-mg/L DCI-4A @ 105°F	6-1	2150	1850	Pass	Pass	Pass	Pass	Pass	Pass
			6-2	2150	1750	Pass	Pass	Pass	Pass	Pass	Pass
			6-3	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			6-4	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			6-5	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			6-6	2100	1800	Pass	Pass	Pass	Pass	Pass	Pass
			6-7	2200	1850	Pass	Pass	Pass	Pass	Pass	Pass
			6-8	2150	1850	Pass	Pass	Pass	Pass	Pass	Pass
6	15396948	Jet A-1 with 22.5-mg/L DCI-4A @ 105°F	6-11	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			6-12	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			6-13	2075	1850	Pass	Pass	Pass	Pass	Pass	Pass
			6-14	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			6-15	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			6-16	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			6-17	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			6-18	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table F-7 and Table F-8.

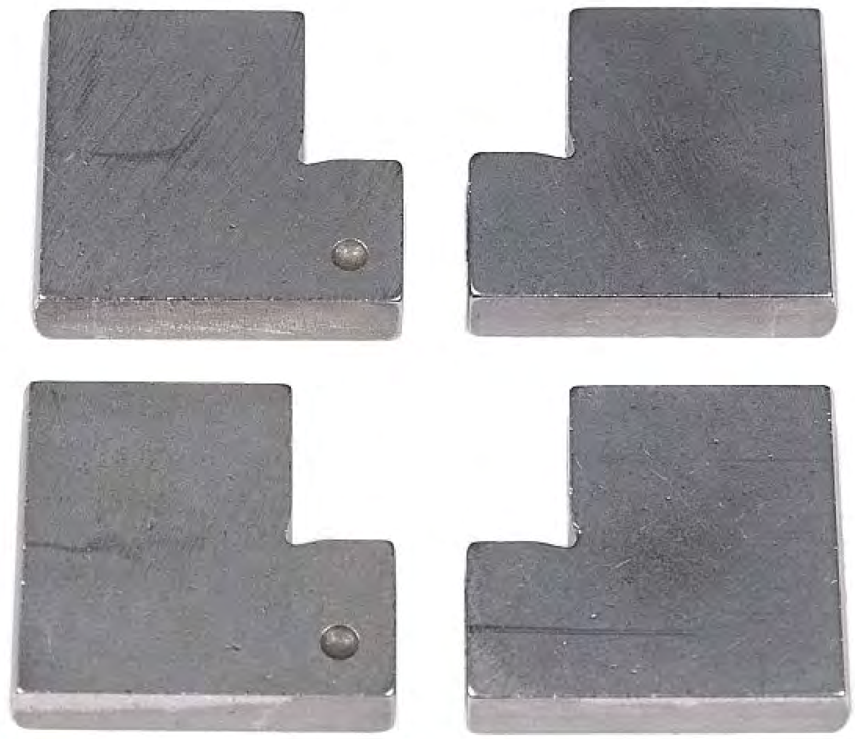
Table F-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079 (arctic)		SN: 15396935
Test Condition : Jet A-1 with 22.5-mg/L DCI-4A @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	No wear	0
LINER	Scarring wear on 80% of surface	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Polishing wear in various spots	1.5
ROTOR	Light wear lines in various spots	1.5
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear in various spots	1.5
PLUNGERS	Polishing wear at end of oposite shoes	1.5
SHOES	Dimple on back, light wear marks from leaf spring	1.5
ROLLERS	No wear, but dark lines showing	1
LEAF SPRING	Light wear from roller contact	1
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Wear from weight contact. Slight groove	1.5
THRUST SLEEVE	Light wear from governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact T washer	1.5
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Scarring wear top right and lower left	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.370

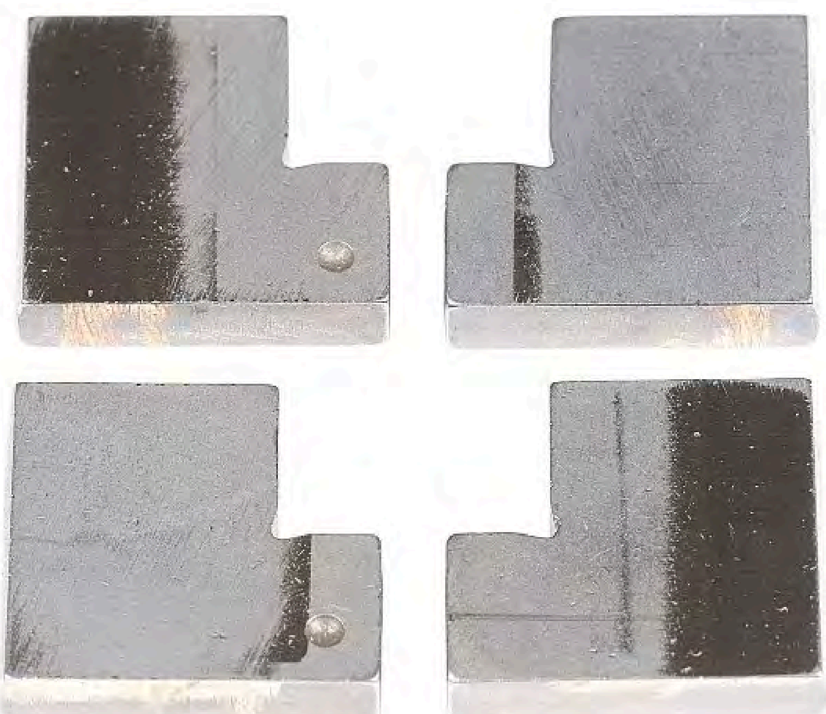
Table F-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079 (arctic)		SN: 15396948
Test Condition : Jet A-1 with 22.5-mg/L DCI-4A @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing Wear	1
LINER	Scarring wear on 80% of surface	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Polishing wear in various spots	1.5
ROTOR	Light wear around distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear	1.5
PLUNGERS	Left-medium polishing wear; right-discloration	2
SHOES	Dimple on back, light wear marks from leaf spring, scorring from rollers	2
ROLLERS	No wear, but dark lines showing and light pitting	1.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Light pitting from rollers	2
THRUST WASHER	Wear from weight contact. Slight groove	1.5
THRUST SLEEVE	Light wear from governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact T washer	1.5
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Scarring wear top right and lower left	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.587

PHOTOGRAPHS FOR LEFT PUMP



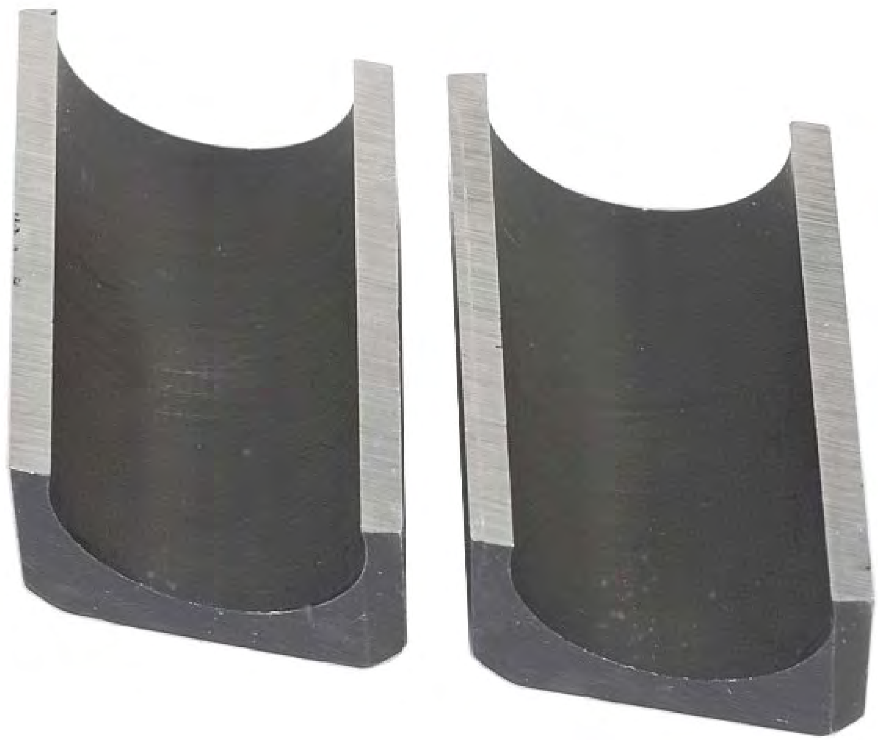
SN15396935 Transfer Pump Blades (Side), Before



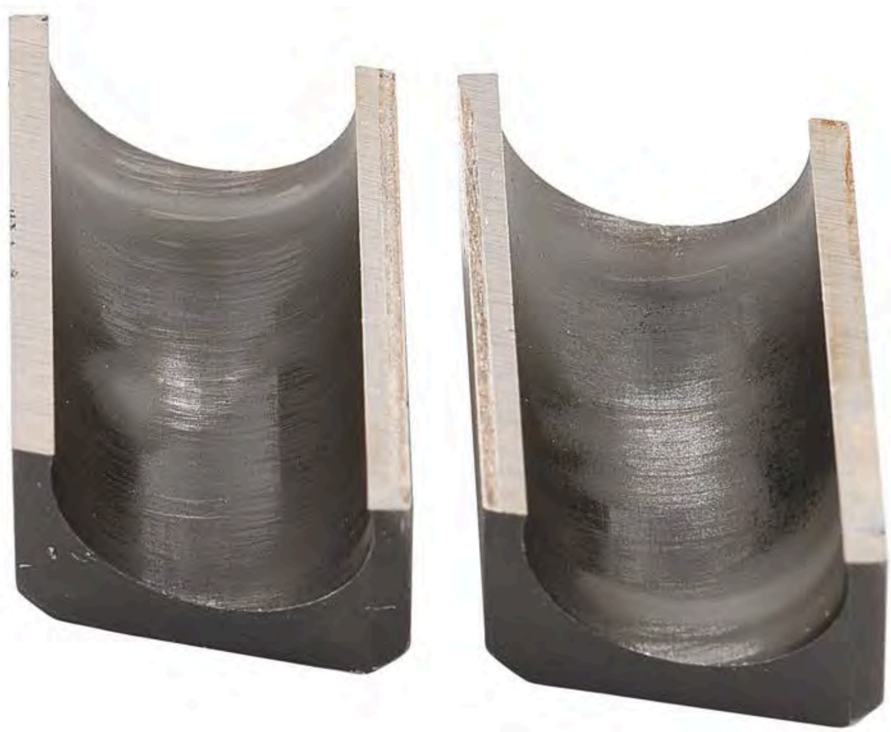
SN15396935 Transfer Pump Blades (Side), After

SN15396935 Transfer Pump Blades (Profile), Before

SN15396935 Transfer Pump Blades (Profile), After

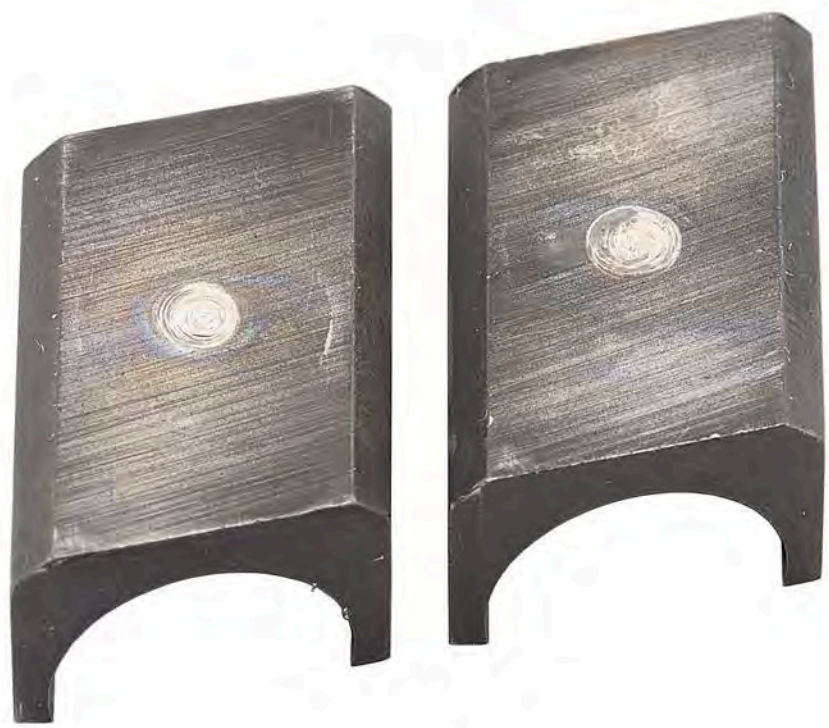


SN15396935 Shoes (Front), Before



SN15396935 Shoes (Front), After

SN15396935 Shoes (Back), Before



SN15396935 Shoes (Back), After

SN15396935 Rollers, Before

SN15396935 Rollers, After

SN15396935 Piston Plungers, Before

SN15396935 Piston Plungers, After

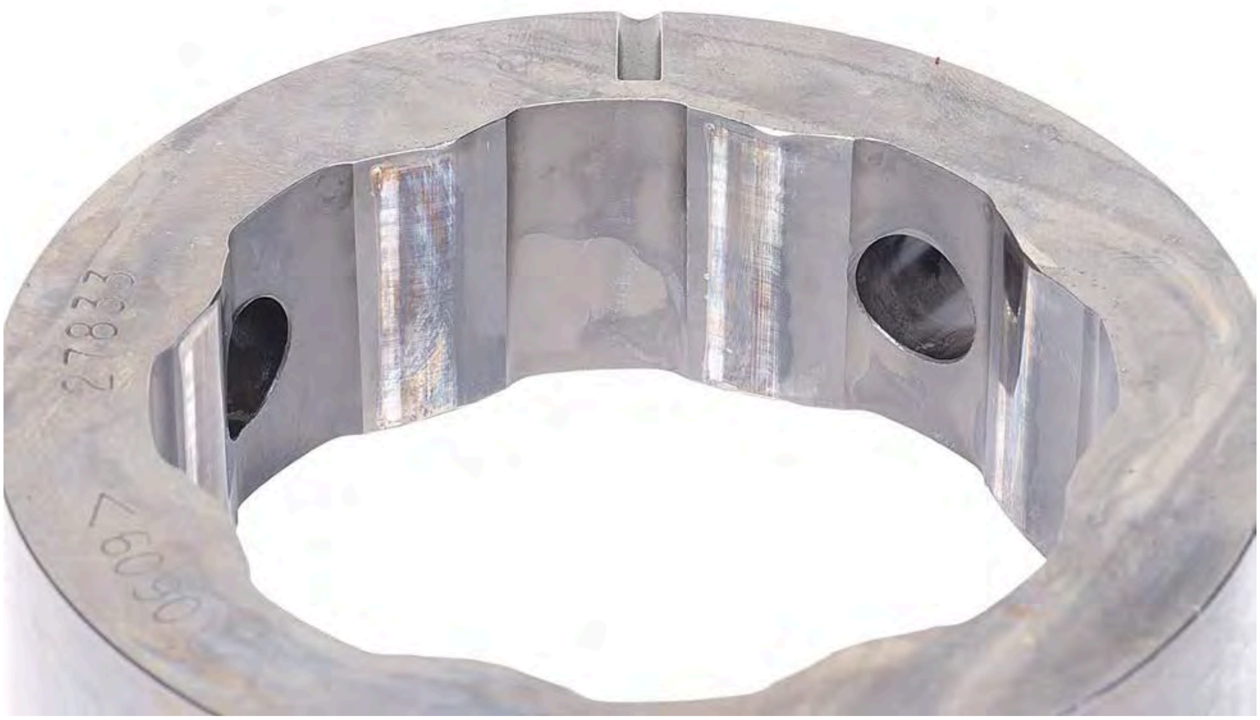
SN15396935 Thrust Washer, Before

SN15396935 Thrust Washer, After

SN15396935 Governor Weight, Before

SN15396935 Governor Weight, After

SN15396935 Cam Ring, Before



SN15396935 Cam Ring, After

SN15396935 Eccentric Ring, Before

SN15396935 Eccentric Ring, After

SN15396935 Rotor (Front), Before

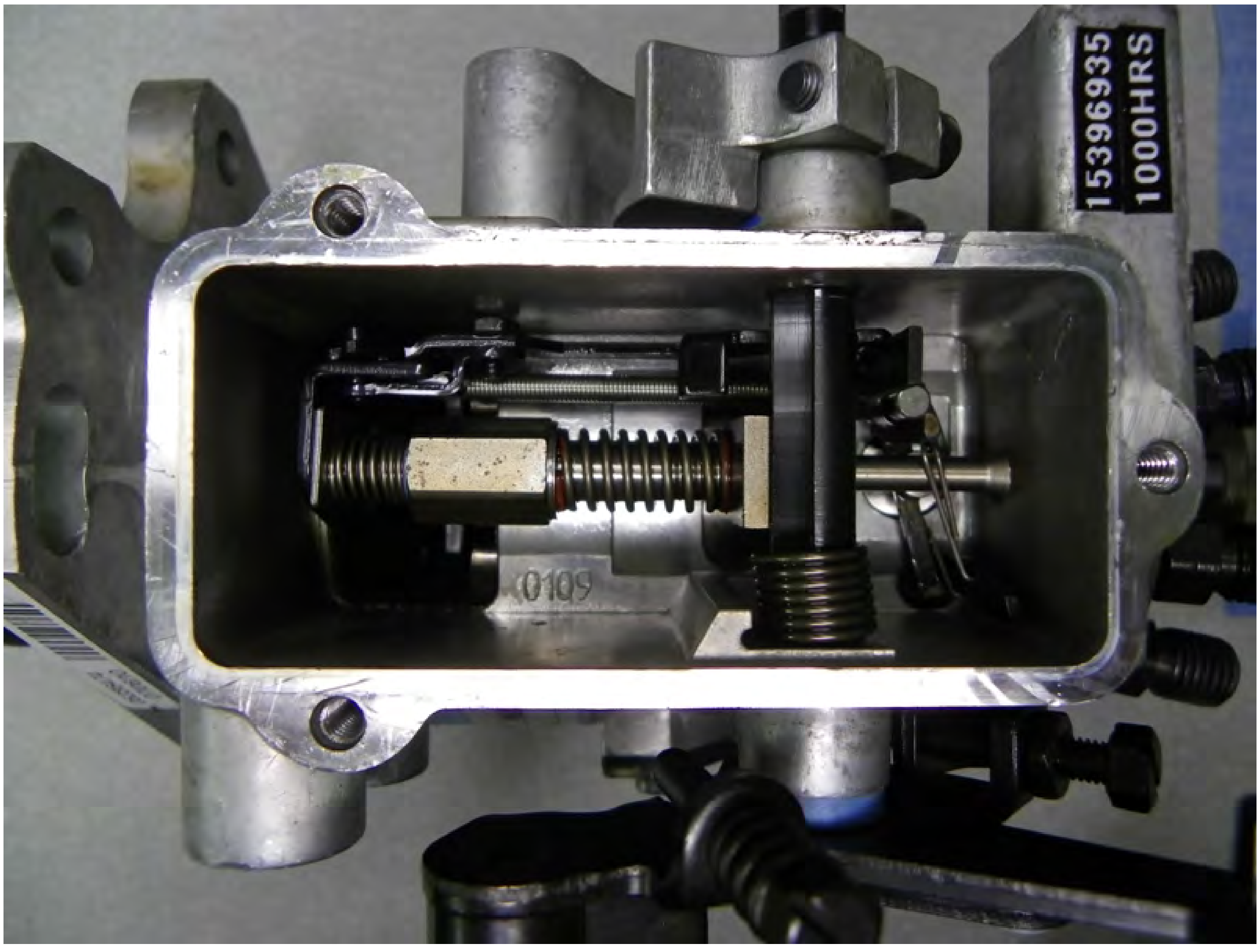
SN15396935 Rotor (Front), After


SN15396935 Rotor (Back), Before


SN15396935 Rotor (Back), After

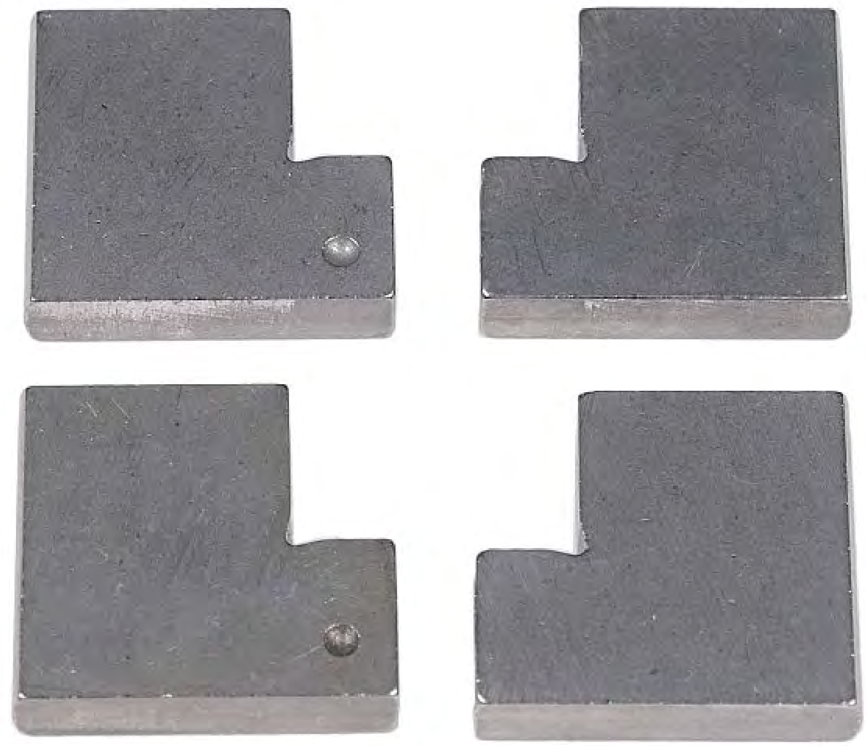
SN15396935 Drive Tang, Before

SN15396935 Drive Tang, After

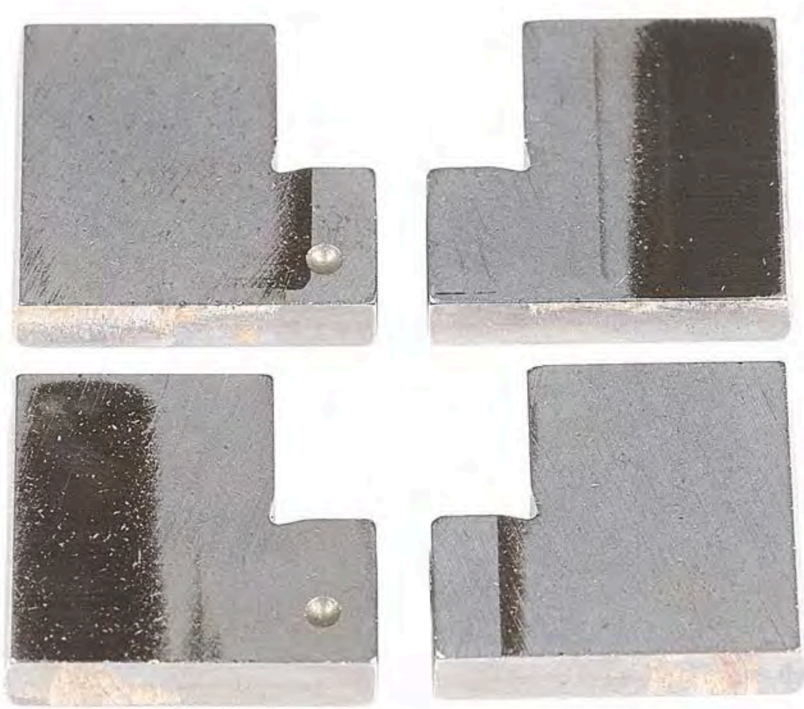


SN15396935 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



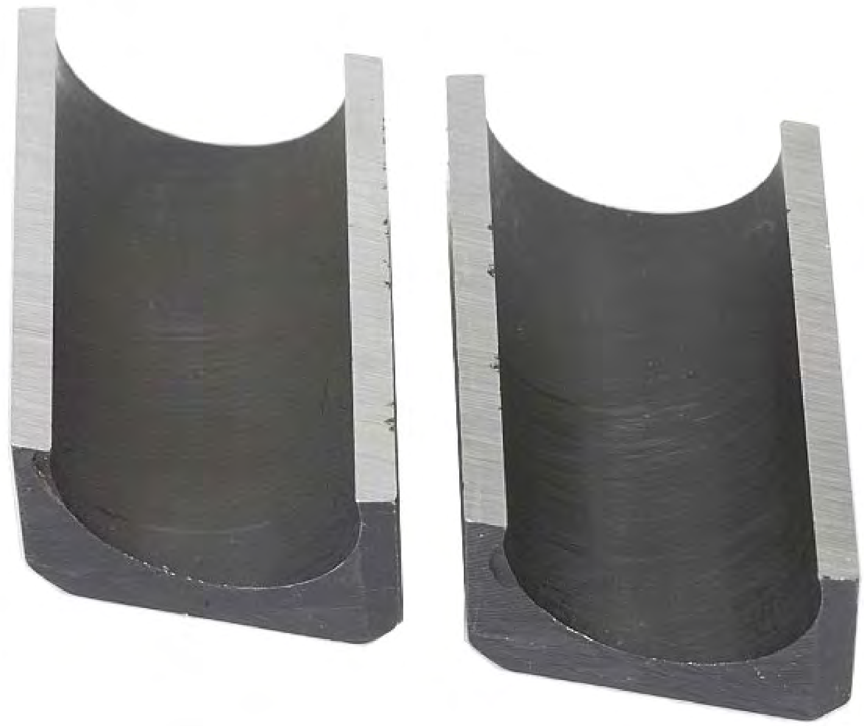
SN15396948 Transfer Pump Blades, Before



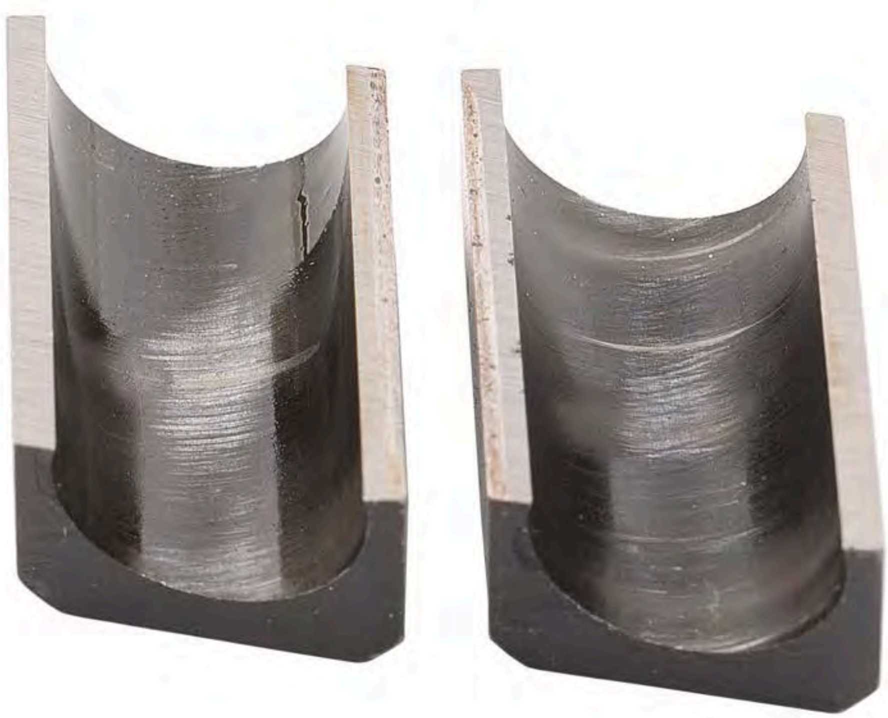
SN15396948 Transfer Pump Blades, After

SN15396948 Transfer Pump Blades (Profile), Before

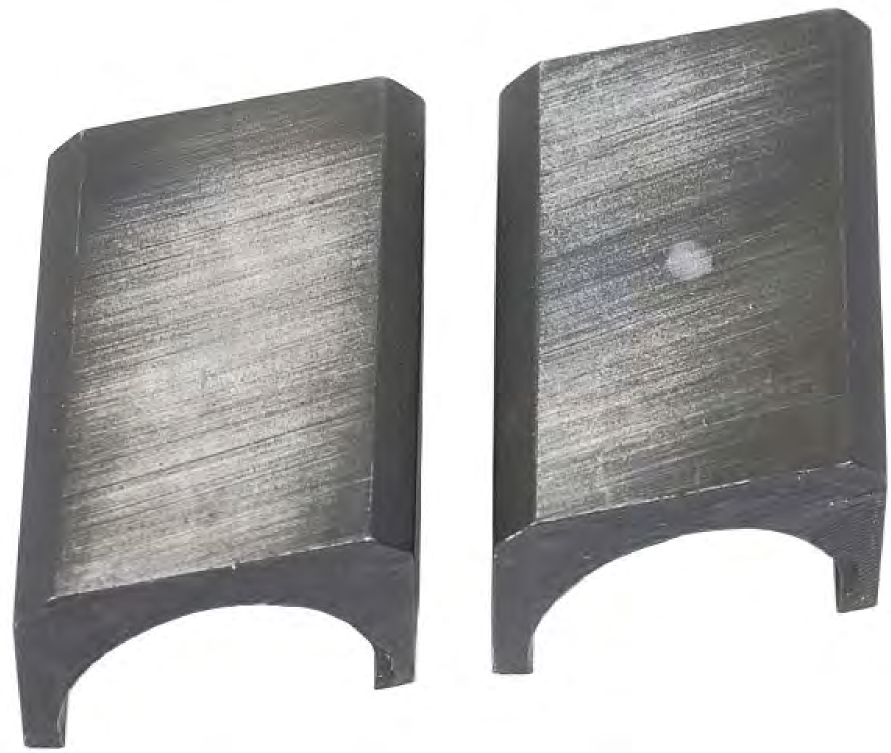
SN15396948 Transfer Pump Blades (Profile), After



SN15396948 Shoes (Front), Before



SN15396948 Shoes (Front), After



SN15396948 Shoes (Back), Before

SN15396948 Shoes (Back), After

SN15396948 Rollers, Before

SN15396948 Rollers, After

SN15396948 Piston Plungers, Before

SN15396948 Piston Plungers, After

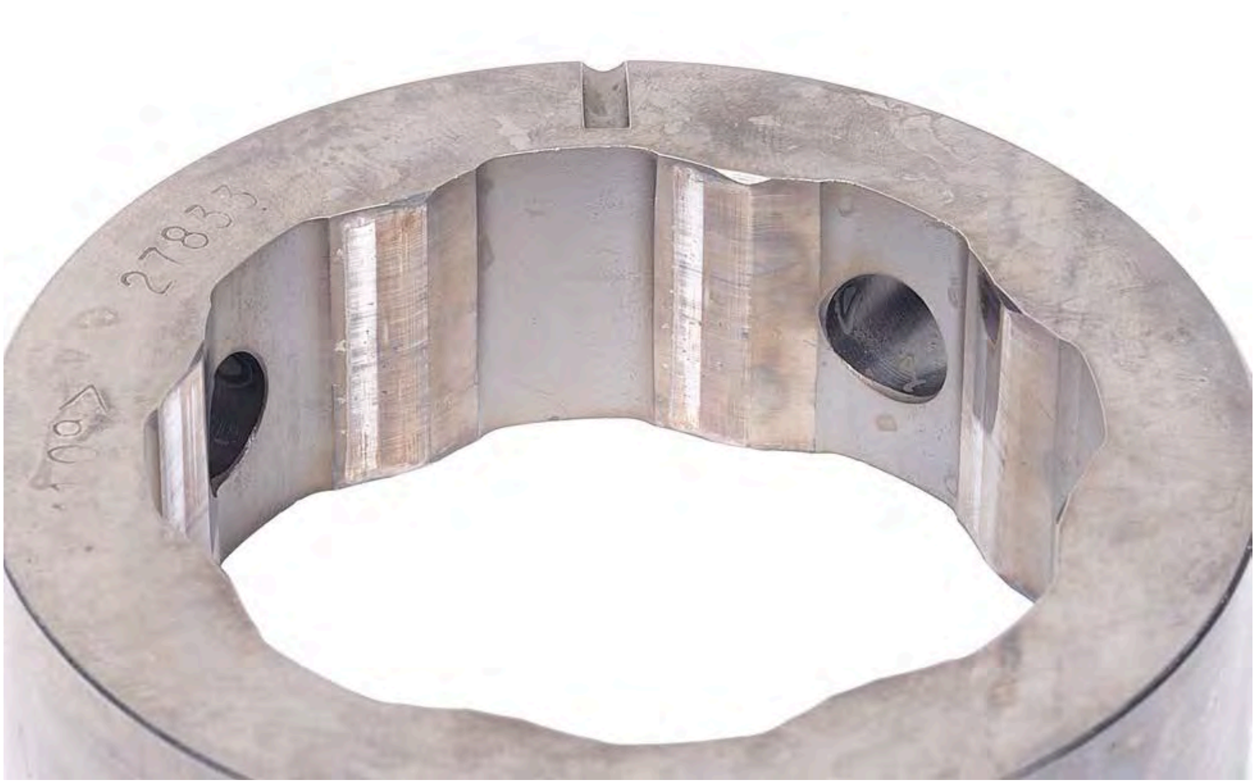
SN15396948 Thrust Washer, Before

SN15396948 Thrust Washer, After

SN15396948 Governor Weight, Before

SN15396948 Governor Weight, After

SN15396948 Cam Ring, Before



SN15396948 Cam Ring, After

SN15396948 Eccentric Ring, Before

SN15396948 Eccentric Ring, After

SN1596948 Rotor (Front), Before

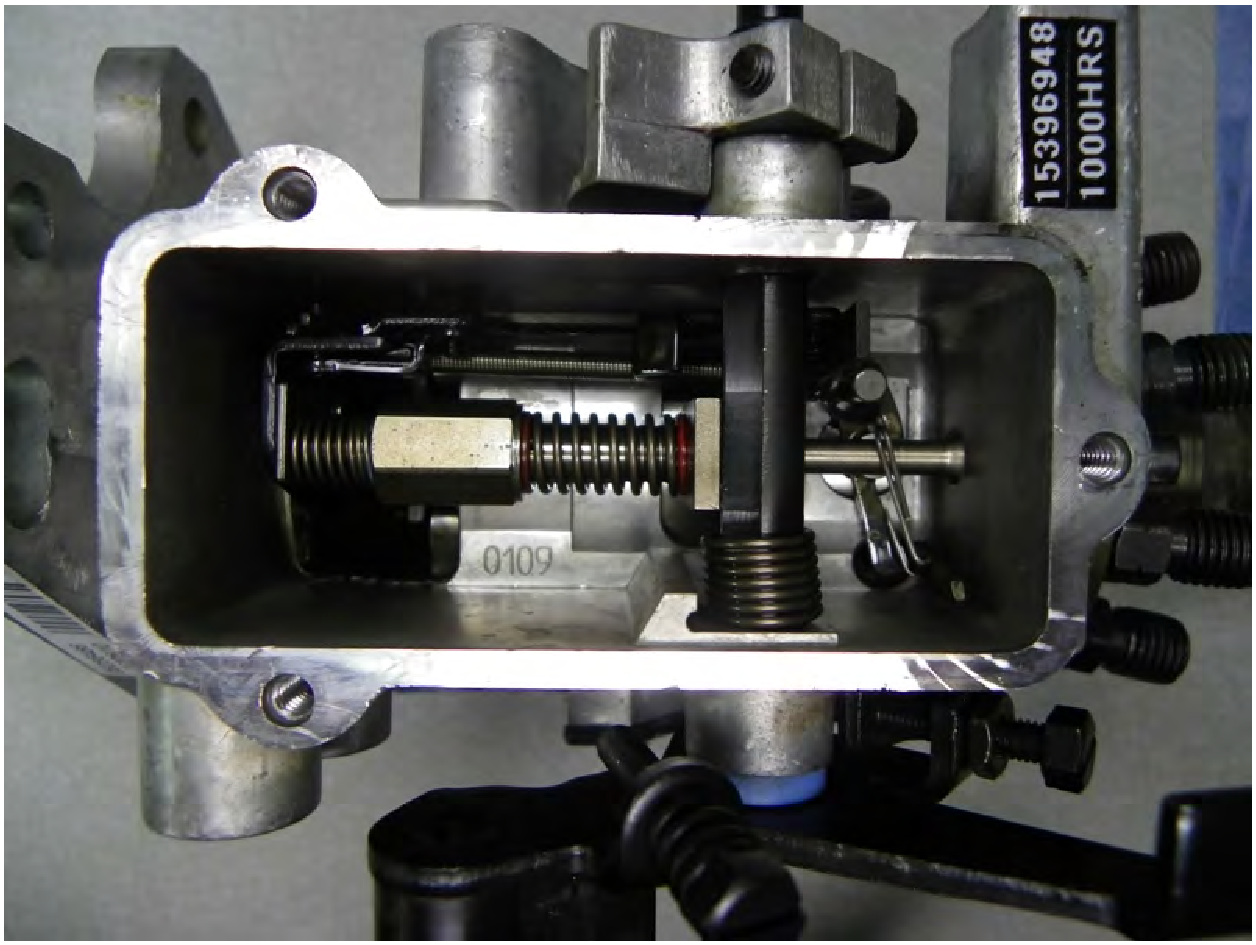
SN1596948 Rotor (Front), After

SN15396948 Rotor (Back), Before

SN15396948 Rotor (Back), After

SN15396948 Drive Tang, Before

SN15396948 Drive Tang, After



SN15396948 Governor Assembly

APPENDIX G

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 25-mg/L Nalco 5403
Test Number: C4T7-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 25-mg/L Nalco 5403

Test Fuel ID: AF7090

Test Temperature: 40°C (104°F)

Test Number: C4T7-40-1000

Start of Test Date: January 31 2011

End of Test Date: April 1, 2011

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure G-11.

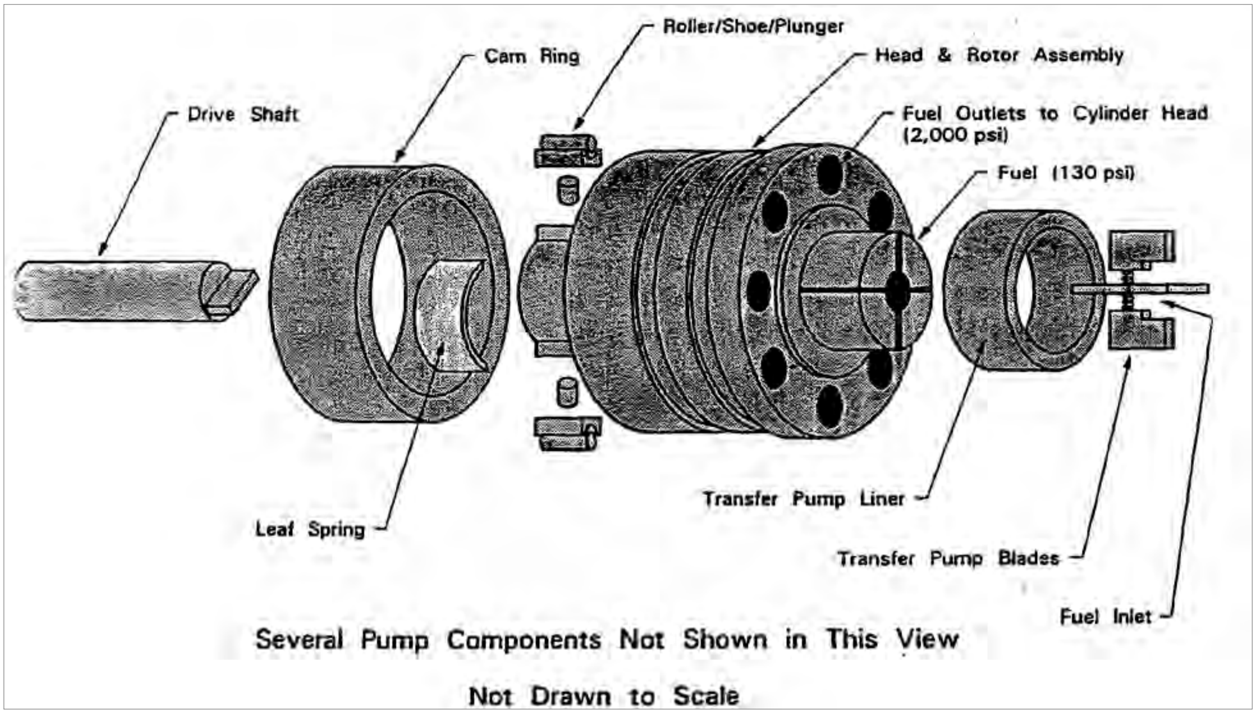


Figure G-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table G-1.

Table G-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table G-2.

Table G-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1701	2.25
FLO_R	Injected Flow-rate [mL/min]	790.85	16.8
FUELIN_P	Fuel Inlet Pressure [psig]	2.7	0.3
TRNS_P_R	Transfer Pump Pressure [psig]	72.9	0.77
HSG_P_R	Pump Housing Pressure [psig]	12.75	0.33
RTRN_T_R	Fuel Return Temperature [°C]	48.1	9.76
FUEL_T	Fuel Tank Temperature [°C]	41.3	32.3
FUELIN_T	Fuel Inlet Temperature [°C]	40.0	0.49

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure G-2 through Figure G-4.

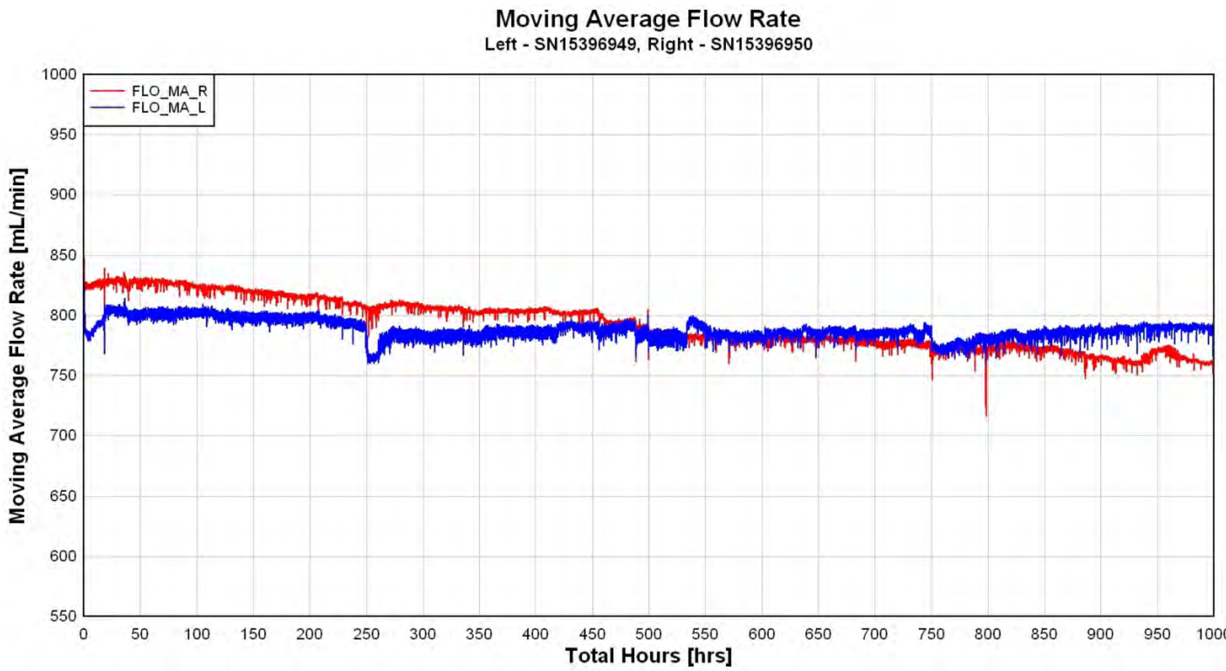


Figure G-2. Pump Flow, Moving Average

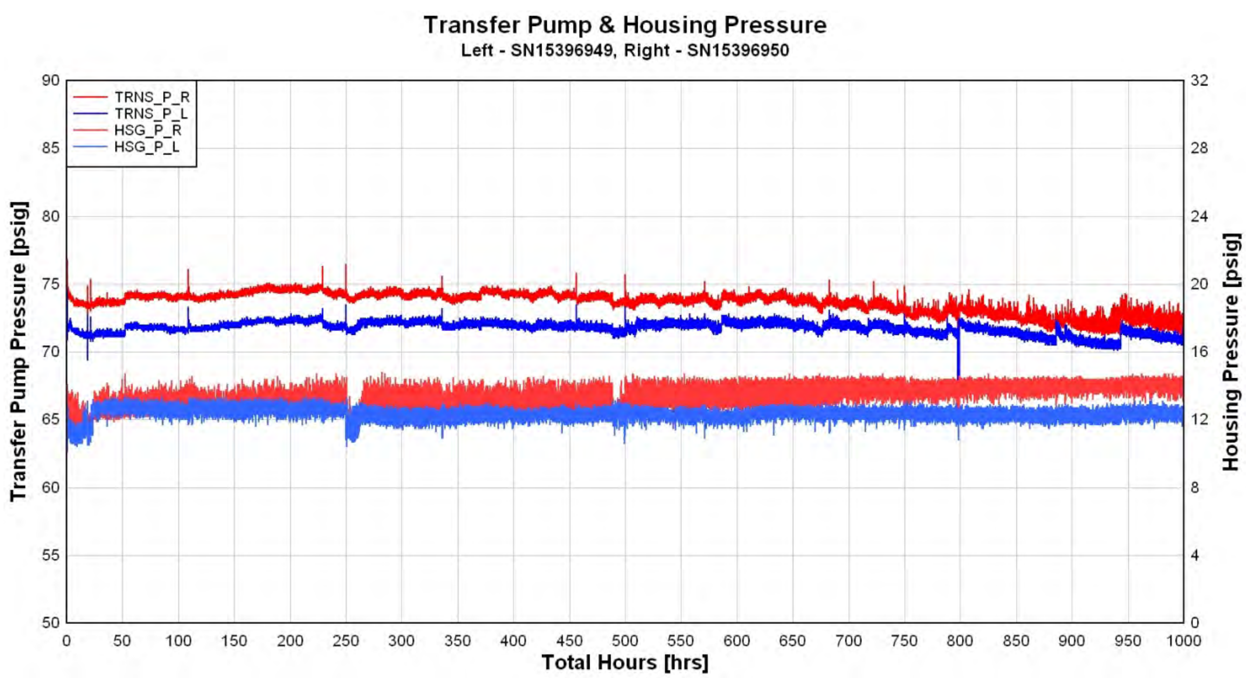


Figure G-3. Transfer Pump & Housing Pressure

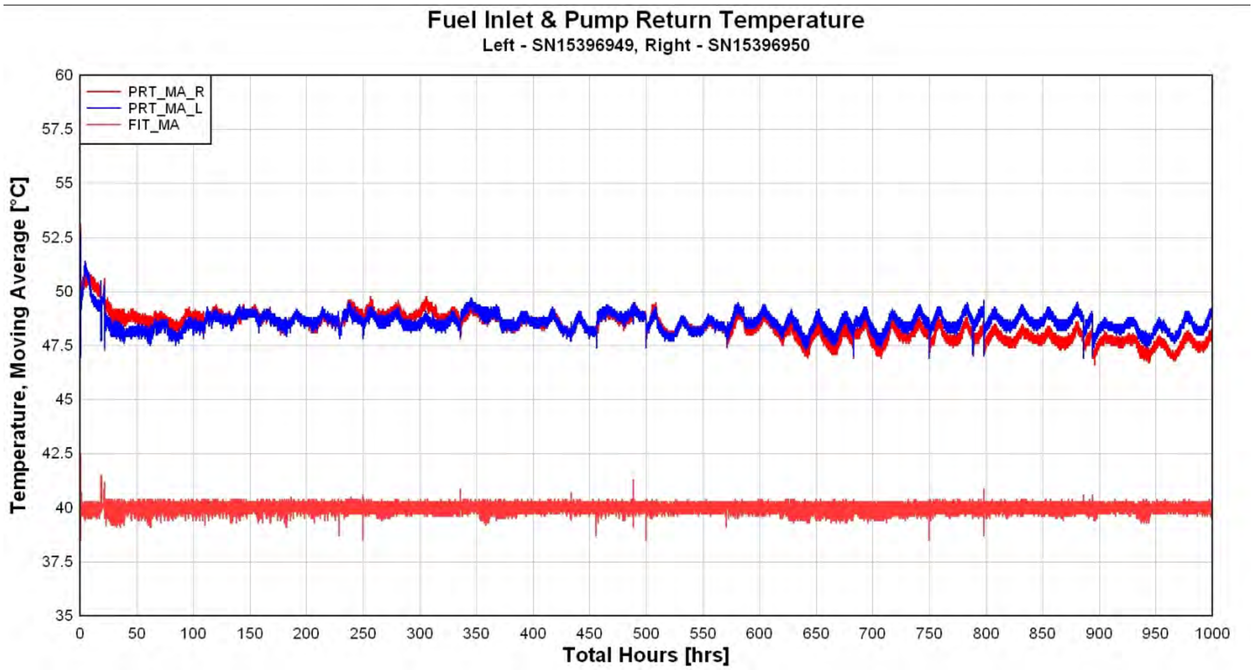


Figure G-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table G-3. (Note – Calibration data to be used as reference only).

Table G-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 7			Test Duration : 1000-hrs.		
Test Fuel : Jet A-1 w/25-mg/L NALCO 5403 @ 105°F				SN : 15396949			SN : 15396950		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	61 psi	1 psi	62 psi	62 psi	psi
	Return Fuel	225 cc	375 cc	350 cc	**395 cc**	-45 cc	290 cc	330 cc	-40 cc
350	Low Idle	12 cc	16 cc	16 cc	13 cc	3 cc	12 cc	**7 cc**	5 cc
	Housing psi.	8 psi	12 psi	9.0 psi	10.0 psi	-1.0 psi	10.0 psi	11.0 psi	-1.0 psi
	Advance	3.50°		4.55°	3.91°	.64°	5.10°	5.11°	-.01°
	Cold Advance Solenoid	.0 psi	1.0 psi	.5 psi	.0 psi	.5 psi	.5 psi	.5 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	**64.0 cc**	3.0 cc	69.0 cc	**64.0 cc**	5.0 cc
1600	WOT Fuel delivery	60 cc		63 cc	60 cc	3 cc	65 cc	**59 cc**	6 cc
	WOT Advance	2.50°	3.50°	3.12°	2.79°	.33°	3.50°	3.75°	-.25°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	**21.0 cc**	1.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.60°	5.86°	.74°	6.90°	6.87°	.03°
	Low Idle	11.0°	12.0°	11.3°	11.2°	.1°	11.6°	11.2°	.4°
1825	Fuel Delivery	33 cc		40 cc	58 cc	-18 cc	38 cc	54 cc	-16 cc
1950	High Idle		15 cc	4 cc	14 cc	-10 cc	2 cc	1 cc	1 cc
	Transfer pump psi.		125 psi	104 psi	101 psi	3 psi	104 psi	105 psi	-1 psi
200	WOT Fuel Delivery	58 cc		61 cc	**57 cc**	4 cc	63 cc	**55 cc**	8 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		56 cc	48 cc	8 cc	52 cc	43 cc	9 cc
	Transfer pump psi.	16 psi		28 psi	28 psi	0 psi	28 psi	25 psi	3 psi
	Housing psi.	.0 psi	12 psi	7.0 psi	8 psi	-1 psi	8 psi	2 psi	6 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table G-4 and Table G-5.

Table G-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)	SN: 15396949	Test Number: 7
Fuel Description : Jet A-1 w/25-mg/L NALCO 5403 @ 105°F		

	Date:	10/29/2010	8/11/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2805	3.2729	-0.0076
Measurement 2		3.2805	3.2730	-0.0075
Measurement 3		3.2805	3.2729	-0.0076
Measurement 4		3.2805	3.2730	-0.0075
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2570	3.2525	-0.0045
Measurement 2		3.2571	3.2527	-0.0044
Measurement 3		3.2570	3.2526	-0.0044
Measurement 4		3.2569	3.2526	-0.0043
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2439	3.2376	-0.0063
Measurement 2		3.2440	3.2374	-0.0066
Measurement 3		3.2440	3.2374	-0.0066
Measurement 4		3.2440	3.2373	-0.0067
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2518	3.2537	0.0019
Measurement 2		3.2517	3.2536	0.0019
Measurement 3		3.2518	3.2533	0.0015
Measurement 4		3.2518	3.2534	0.0016
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2805	3.2730	-0.0076
Transfer Pump Blade 2		3.2570	3.2526	-0.0044
Transfer Pump Blade 3		3.2440	3.2374	-0.0066
Transfer Pump Blade 4		3.2518	3.2535	0.0017
	Roller to Roller (in)	1.9676	1.9748	0.0072
	Eccentricity (in.)	0.0070	0.0100	0.0030
	Drive Backlash (In)	0.0050	0.0060	0.0010

Table G-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)	SN: 15396950	Test Number: 7
Fuel Description : Jet A-1 w/25-mg/L NALCO 5403 @ 105°F		

	Date:	9/29/2010	8/25/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2570	3.2542	-0.0028
Measurement 2		3.2570	3.2541	-0.0029
Measurement 3		3.2569	3.2541	-0.0028
Measurement 4		3.2570	3.2542	-0.0028
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2300	3.2295	-0.0005
Measurement 2		3.2300	3.2295	-0.0005
Measurement 3		3.2299	3.2294	-0.0005
Measurement 4		3.2299	3.2295	-0.0004
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2369	3.2354	-0.0015
Measurement 2		3.2369	3.2355	-0.0014
Measurement 3		3.2369	3.2356	-0.0013
Measurement 4		3.2369	3.2355	-0.0014
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2650	3.2623	-0.0027
Measurement 2		3.2651	3.2624	-0.0027
Measurement 3		3.2650	3.2623	-0.0027
Measurement 4		3.2651	3.2623	-0.0028
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2570	3.2542	-0.0028
Transfer Pump Blade 2		3.2300	3.2295	-0.0005
Transfer Pump Blade 3		3.2369	3.2355	-0.0014
Transfer Pump Blade 4		3.2651	3.2623	-0.0027
	Roller to Roller (in)	1.9760	1.9370	-0.0390
	Eccentricity (in.)	0.0070	0.0100	0.0030
Note: Stained brown	Drive Backlash (In)	0.0004	ND	

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table G-6.

Table G-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection												
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
7	15396949	Jet A-1 w/25-mg/L NALCO 5403 @ 105°F	7-1	2100	1700	Pass	Pass	Pass	Pass	Pass	Pass
			7-2	2050	1650	Pass	Pass	Pass	Pass	Pass	Pass
			7-3	2150	1725	Pass	Pass	Pass	Pass	Pass	Pass
			7-4	2150	1525	Pass	Pass	Pass	Pass	Pass	Pass
			7-5	2150	1725	Pass	Pass	Pass	Pass	Pass	Pass
			7-6	2125	1700	Pass	Pass	Pass	Pass	Pass	Pass
			7-7	2125	1725	Pass	Pass	Pass	Pass	Pass	Pass
			7-8	2025	1700	Pass	Pass	Pass	Pass	Pass	Pass
7	15396950	Jet A-1 w/25-mg/L NALCO 5403 @ 105°F	7-11	2050	1575	Pass	Pass	Pass	Pass	Pass	Pass
			7-12	2125	1550	Pass	Pass	Pass	Pass	Pass	Pass
			7-13	2200	1675	Pass	Pass	Pass	Pass	Pass	Pass
			7-14	2150	1675	Pass	Pass	Pass	Pass	Pass	Pass
			7-15	2050	1525	Pass	Pass	Pass	Pass	Pass	Pass
			7-16	2125	1600	Pass	Pass	Pass	Pass	Pass	Pass
			7-17	2125	1575	Pass	Pass	Pass	Pass	Pass	Pass
			7-18	2200	1675	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments : ____________________

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table G-7 and Table G-8.

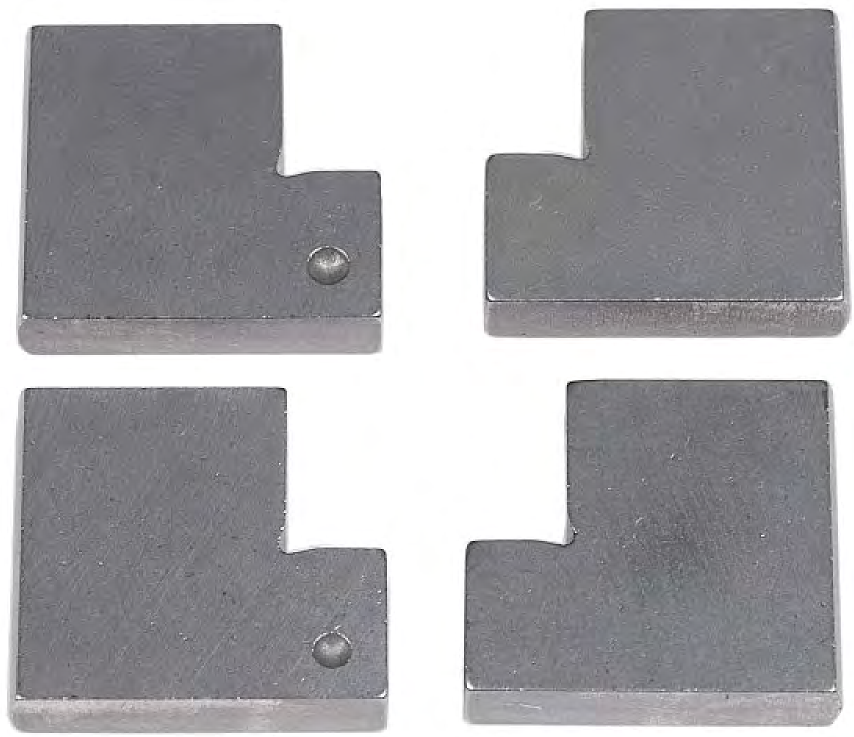
Table G-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2-5079 (Arctic)		SN: 15396949
Test Condition : Jet A-1 w/25-mg/L NALCO 5403 @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing Wear	1
LINER	Scarring wear on 80% of surface	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Polishing wear in various spots	1.5
ROTOR	Wear marks at inlet and outlet ports	2.5
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Left - dicolored and worn, right- polishing wear	2.5
SHOES	Dimple on back, light wear marks from leaf spring, scorring from rollers	2
ROLLERS	No wear, but dark lines showing and light pitting	1.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Wear from weight contact. Slight groove	1.5
THRUST SLEEVE	Light wear from governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact T washer	2
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Scarring wear top right and lower left	3
HOUSING	Normal, light brown stain	1
	AVERAGE DEMERIT RATINGS	1.630

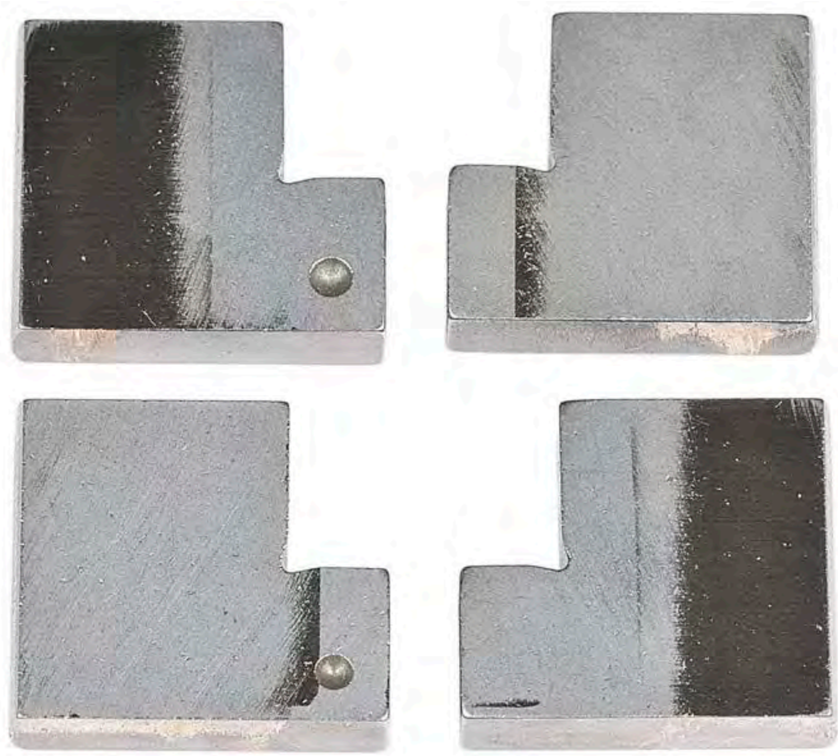
Table G-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2-5079 (Arctic)		SN: 15396950
Test Condition : Jet A-1 w/25-mg/L NALCO 5403 @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	No wear	1
LINER	Scarring wear on 80% of surface	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Scuffing marks at two areas	2
ROTOR	Wear marks at outlet ports	2
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear in various spots	1.5
PLUNGERS	Light polighing	1
SHOES	Dimple on back, light wear marks from leaf spring, scorring from rollers	1.5
ROLLERS	No wear - Dark lines	1
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Normal polishing wear from rollers	1
THRUST WASHER	Polishing wear from weight from weights	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	1.5
LINK HOOK	Normal	1
METERING VAVLE	Slight polihing wear - Brown stain at helix	1
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Scarring wear top right and lower left	3
HOUSING	Normal - Light brown stain	1
	AVERAGE DEMERIT RATINGS	1.435

PHOTOGRAPHS FOR LEFT PUMP



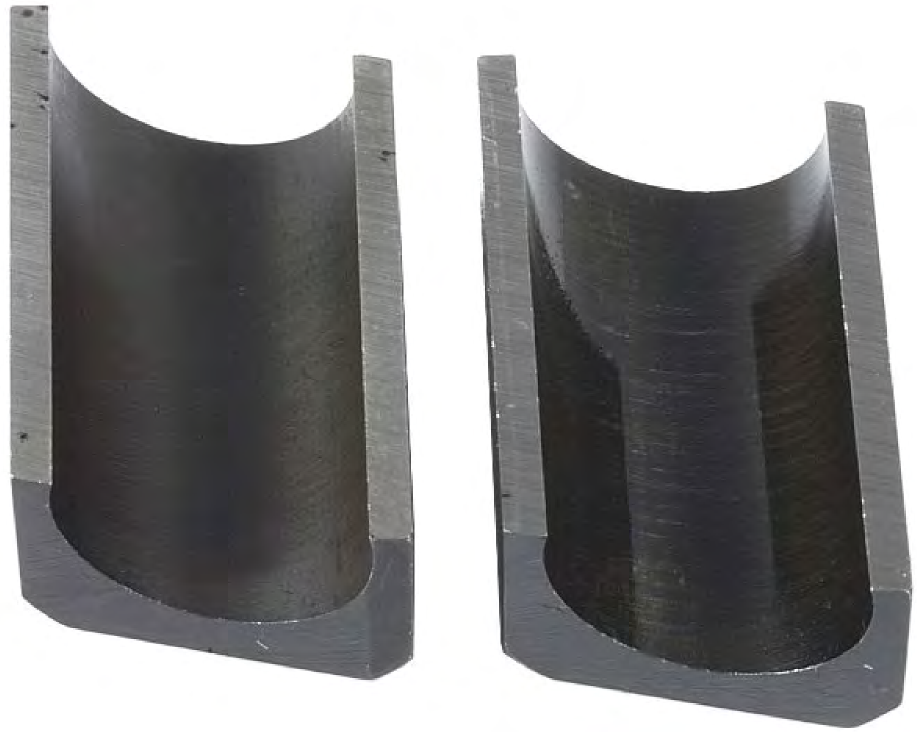
SN15396949 Transfer Pump Blades (Side), Before



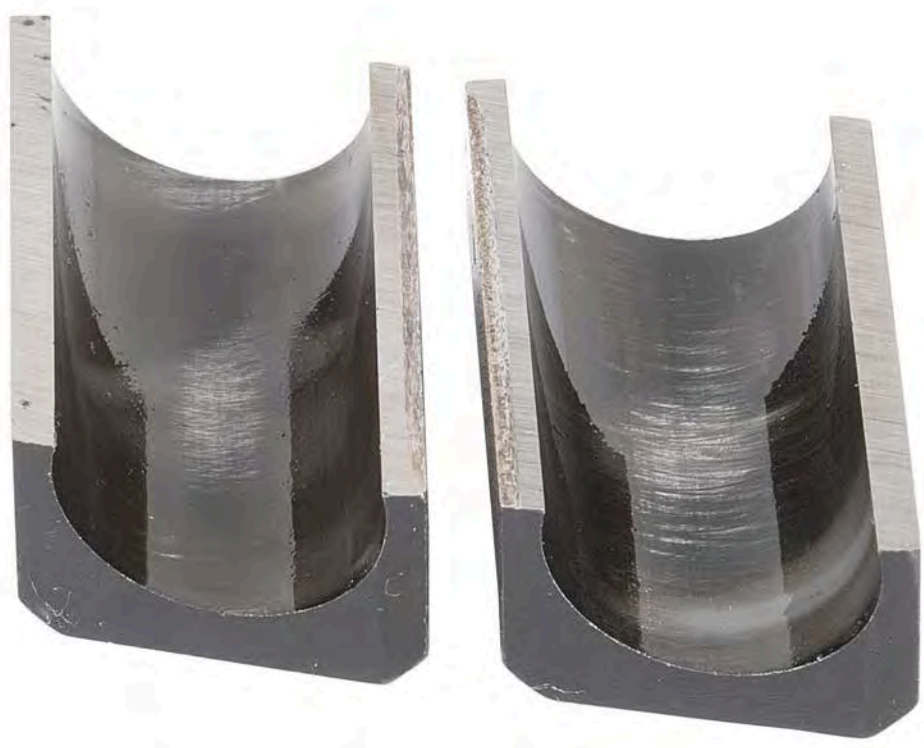
SN15396949 Transfer Pump Blades (Side), After

SN15396949 Transfer Pump Blades (Profile), Before

SN15396949 Transfer Pump Blades (Profile), After

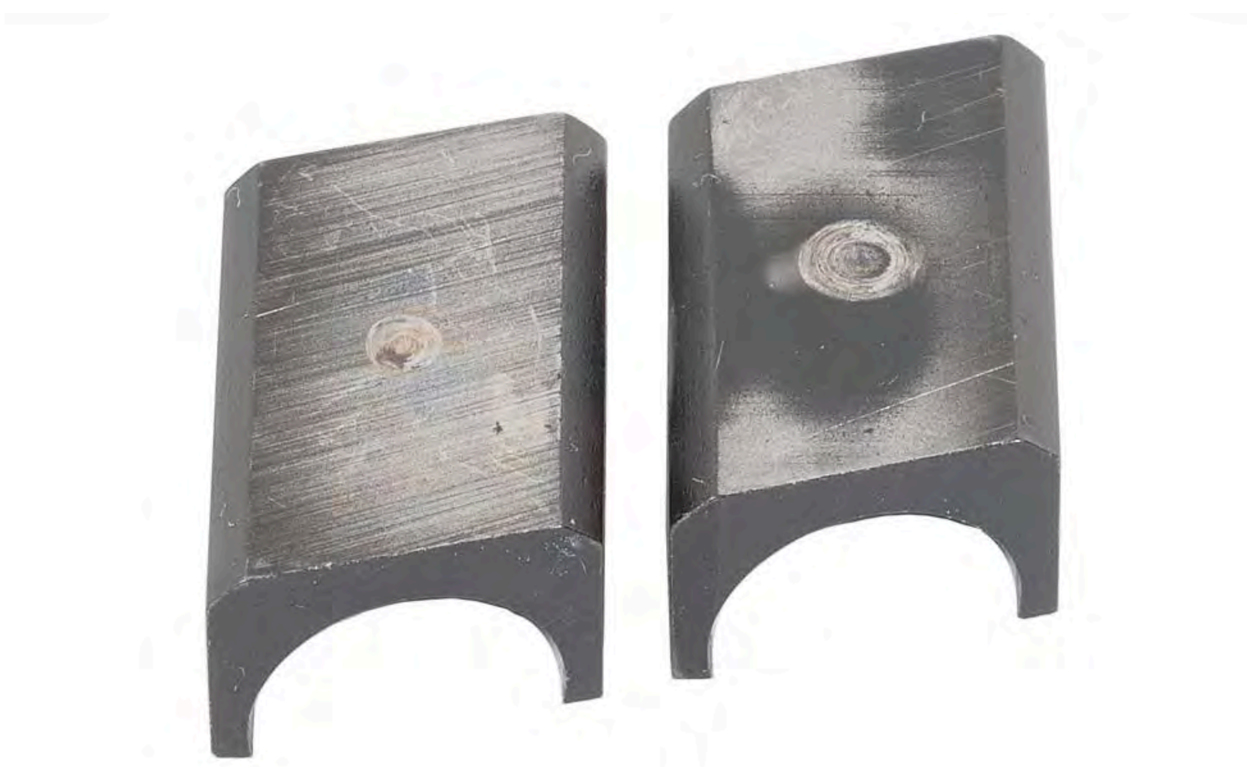


SN15396949 Shoes (Front), Before



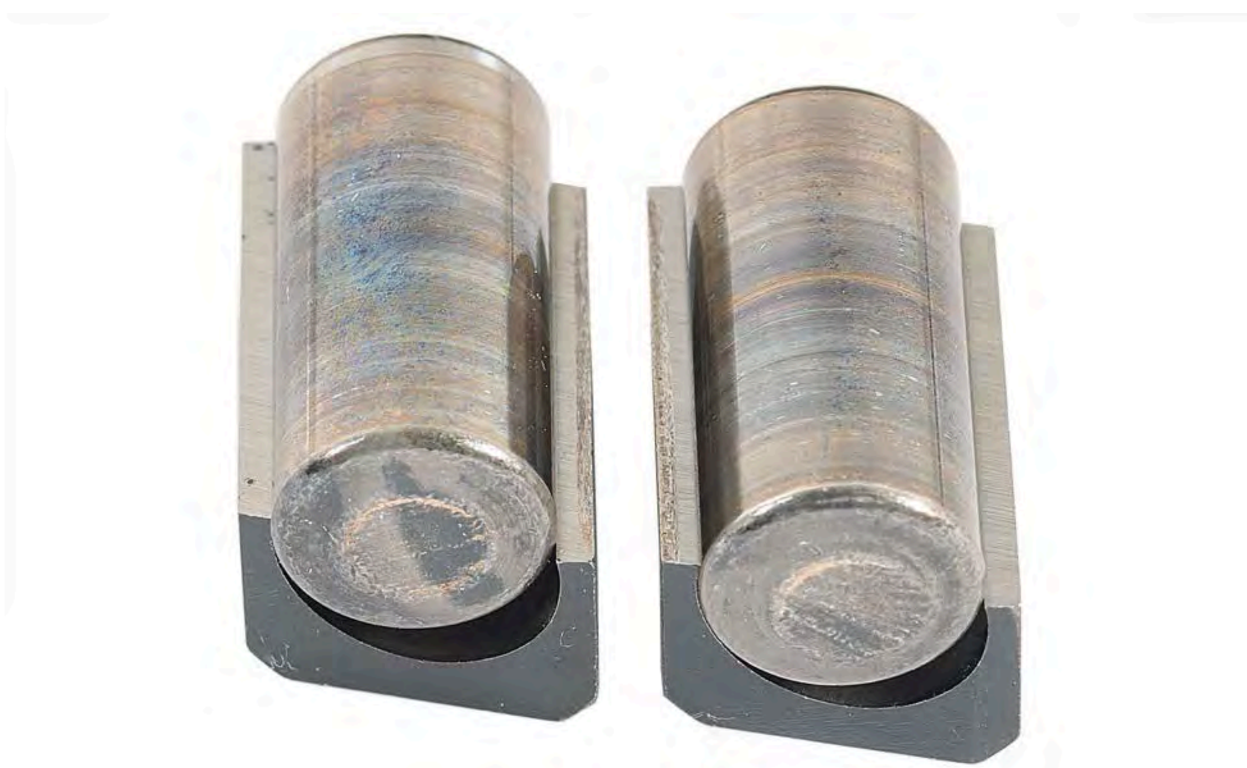
SN15396949 Shoes (Front), After

SN15396949 Shoes (Back), Before



SN15396949 Shoes (Back), After

SN15396949 Rollers, Before



SN15396949 Rollers, After

SN15396949 Piston Plungers, Before

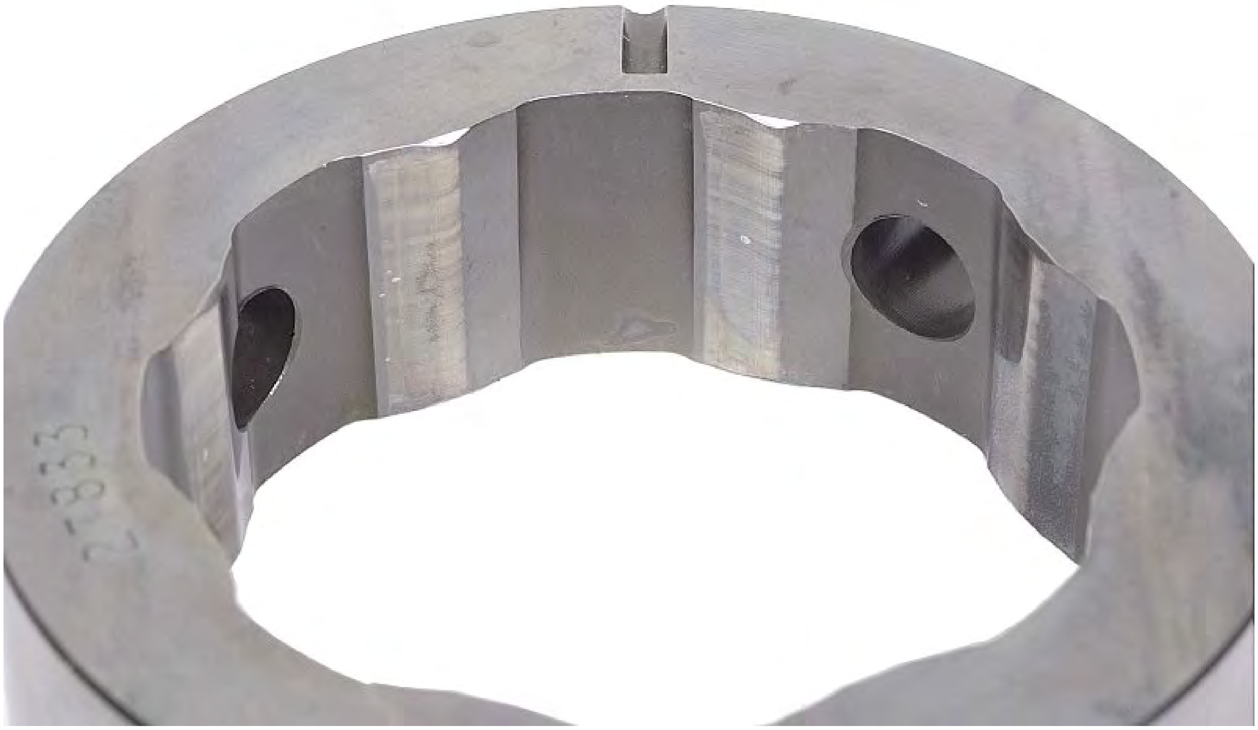
SN15396949 Piston Plungers, After

SN15396949 Thrust Washer, Before

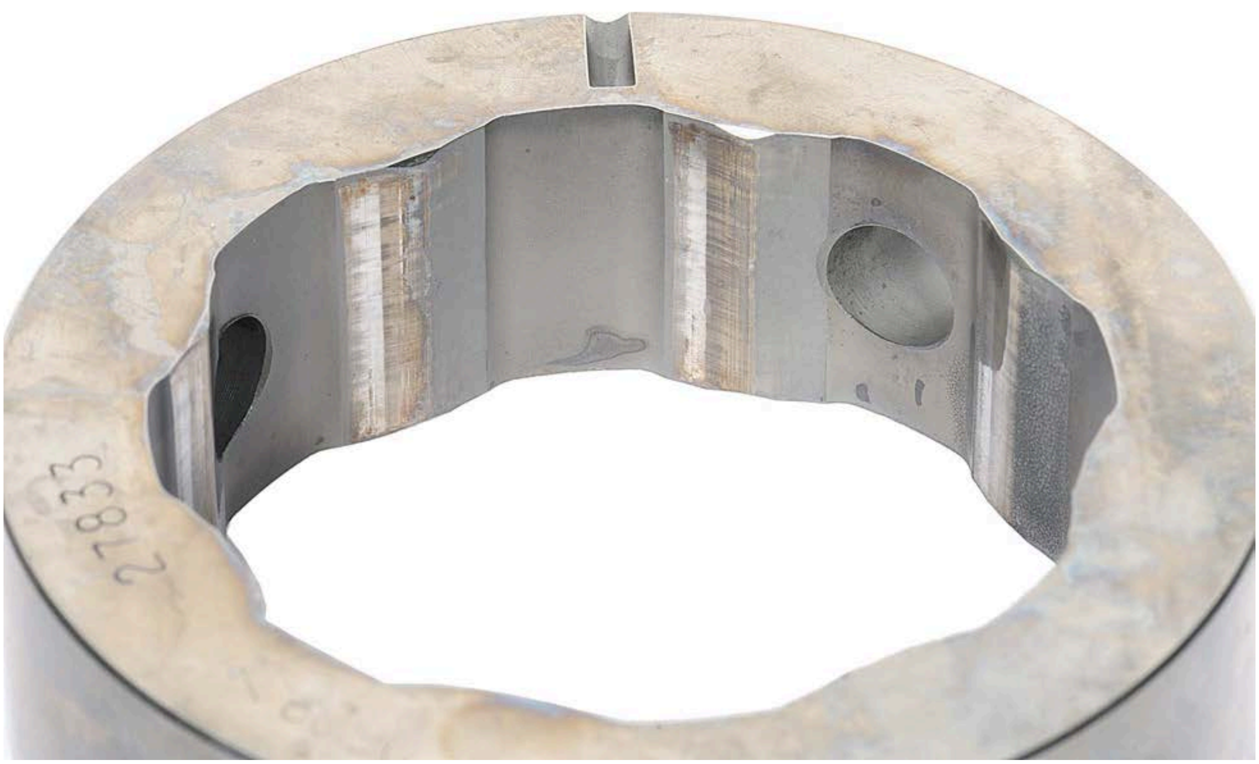
SN15396949 Thrust Washer, After

SN15396949 Governor Weight, Before

SN15396949 Governor Weight, After



SN15396949 Cam Ring, Before



SN15396949 Cam Ring, After

SN15396949 Eccentric Ring, Before

SN15396949 Eccentric Ring, After

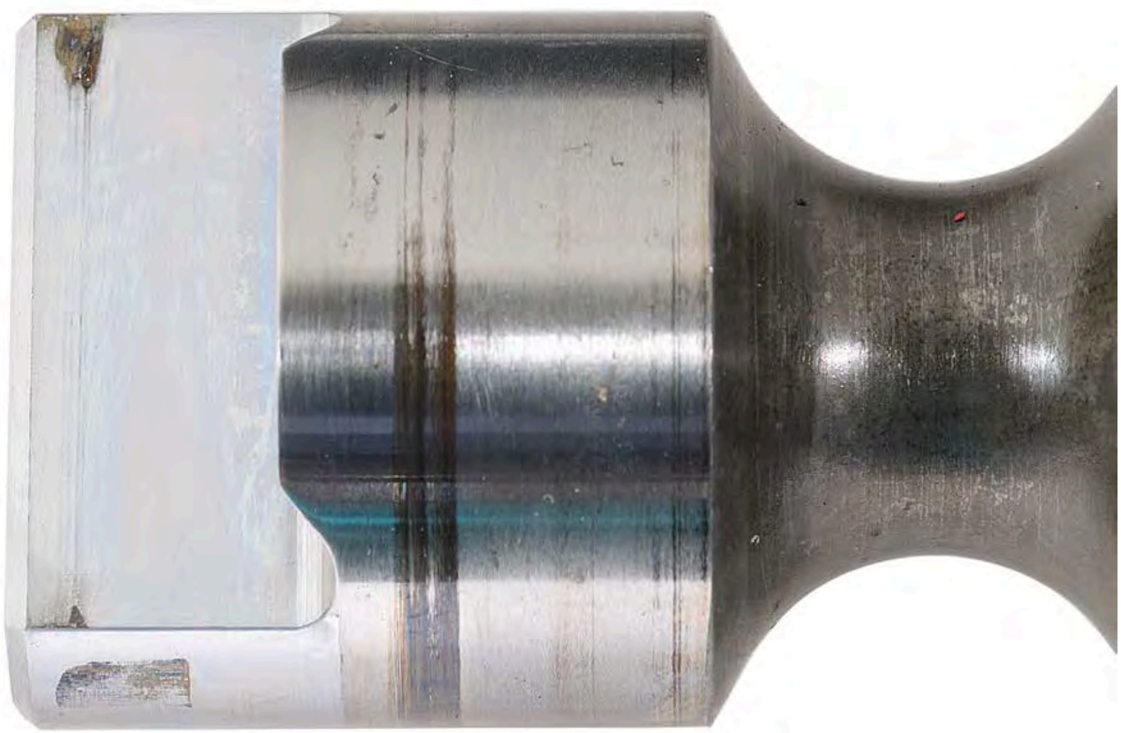
SN15396949 Rotor (Front), Before

SN15396949Rotor (Front), After

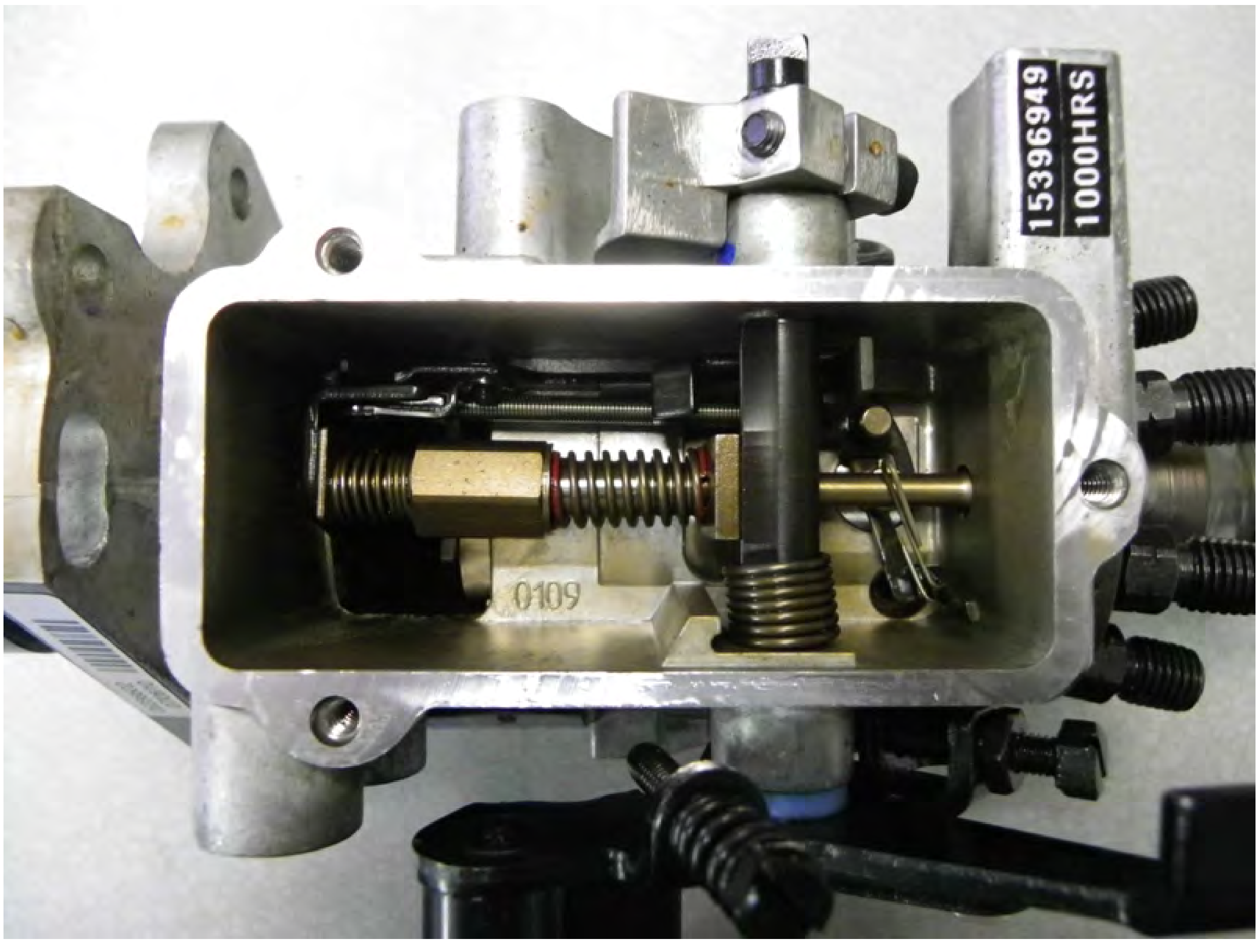
SN15396949 Rotor (Back), Before

SN15396949 Rotor (Back), After

SN15396949 Drive Tang, Before

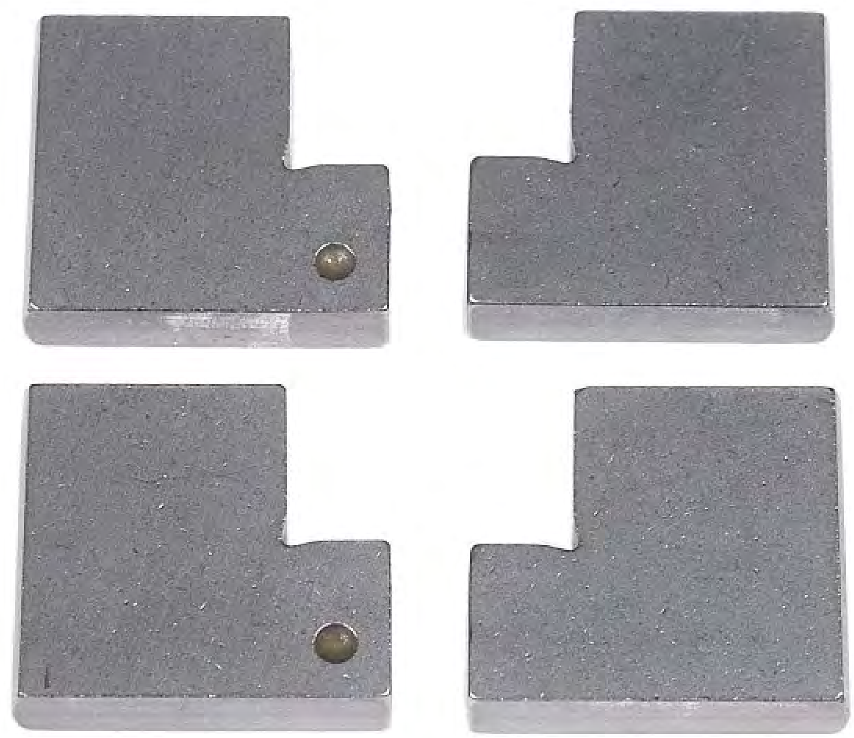


SN15382749 Drive Tang, After

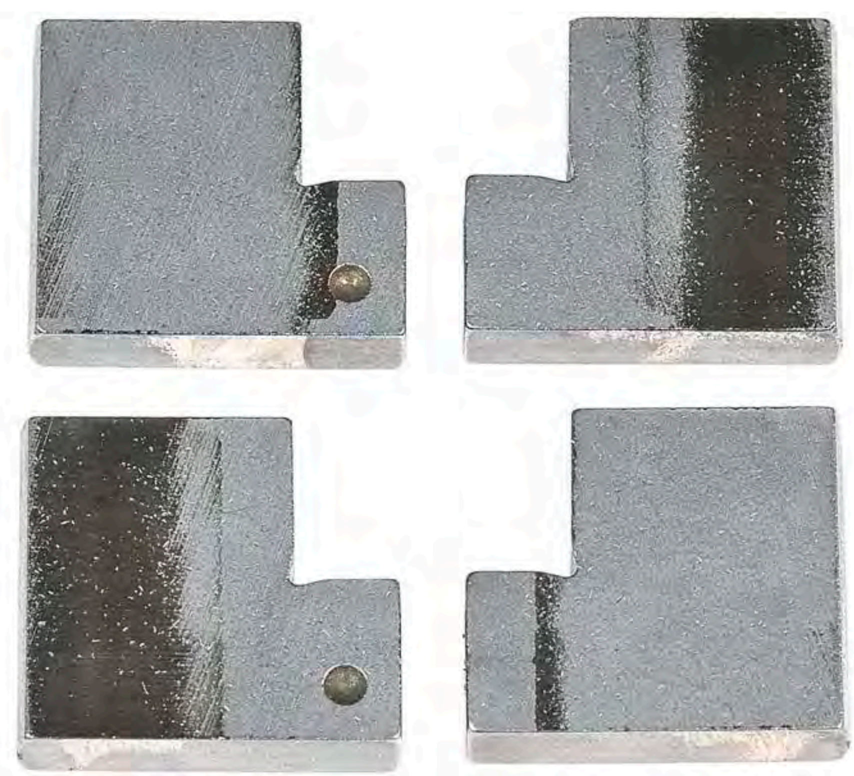


SN15396949 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



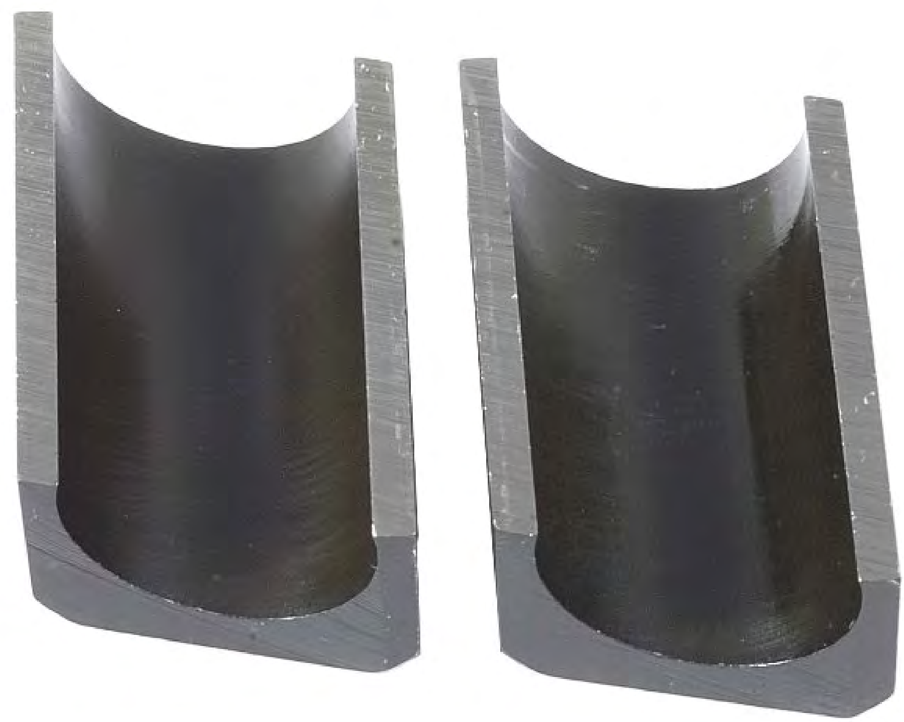
SN15396950 Transfer Pump Blades, Before



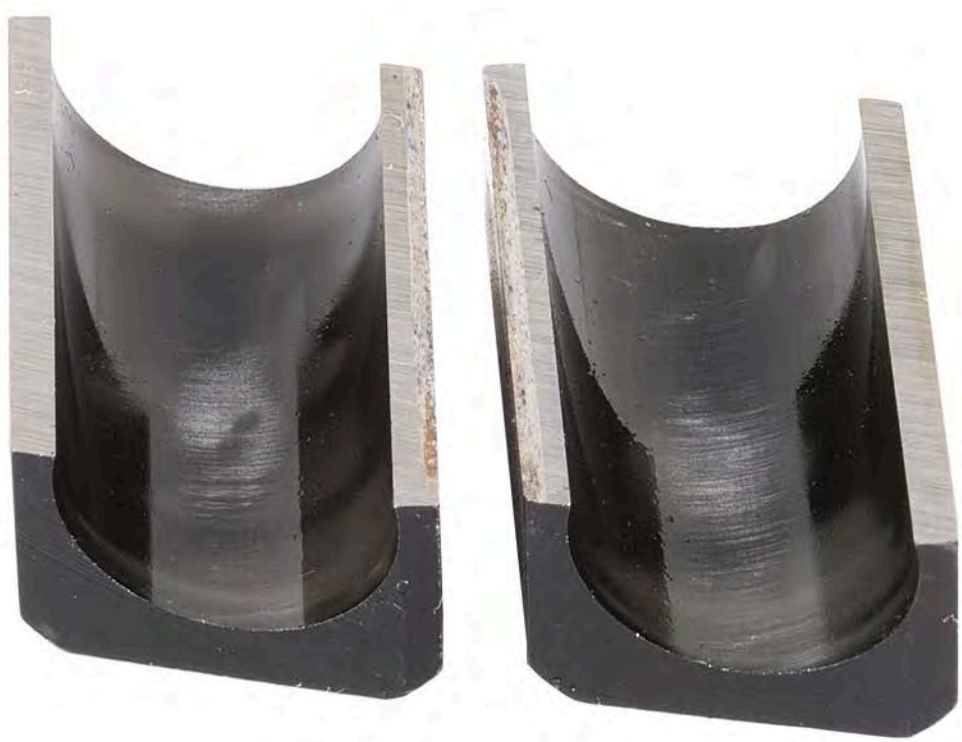
SN15396950 Transfer Pump Blades, After

SN15396950 Transfer Pump Blades (Profile), Before

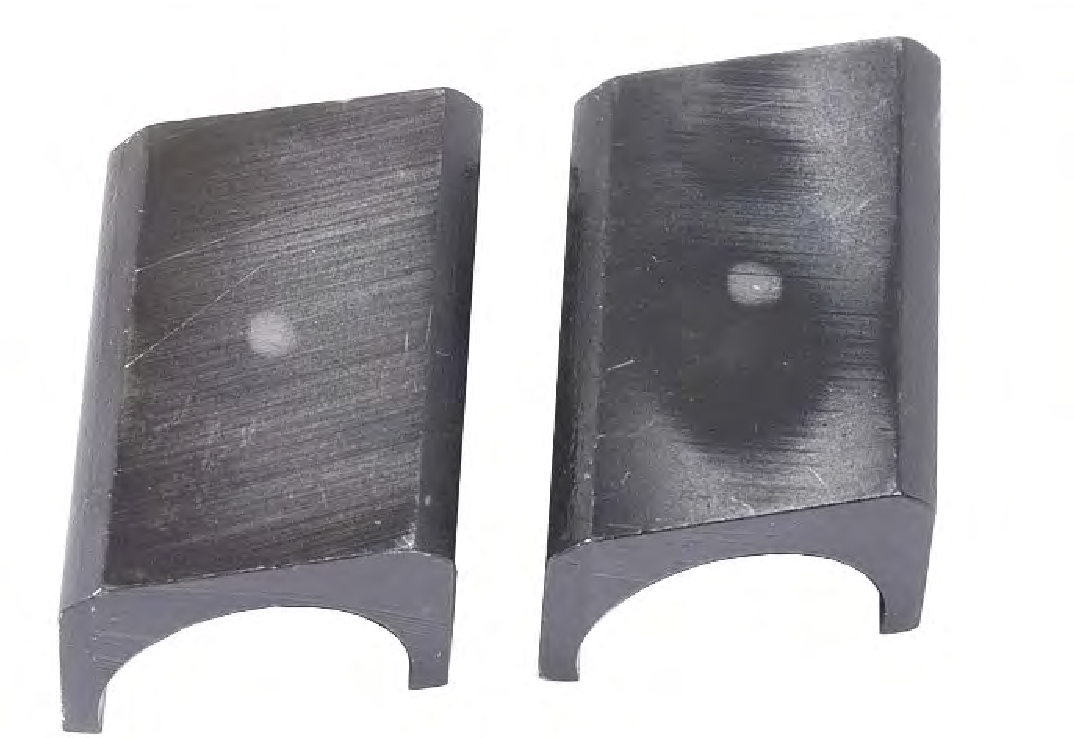
SN15396950 Transfer Pump Blades (Profile), After



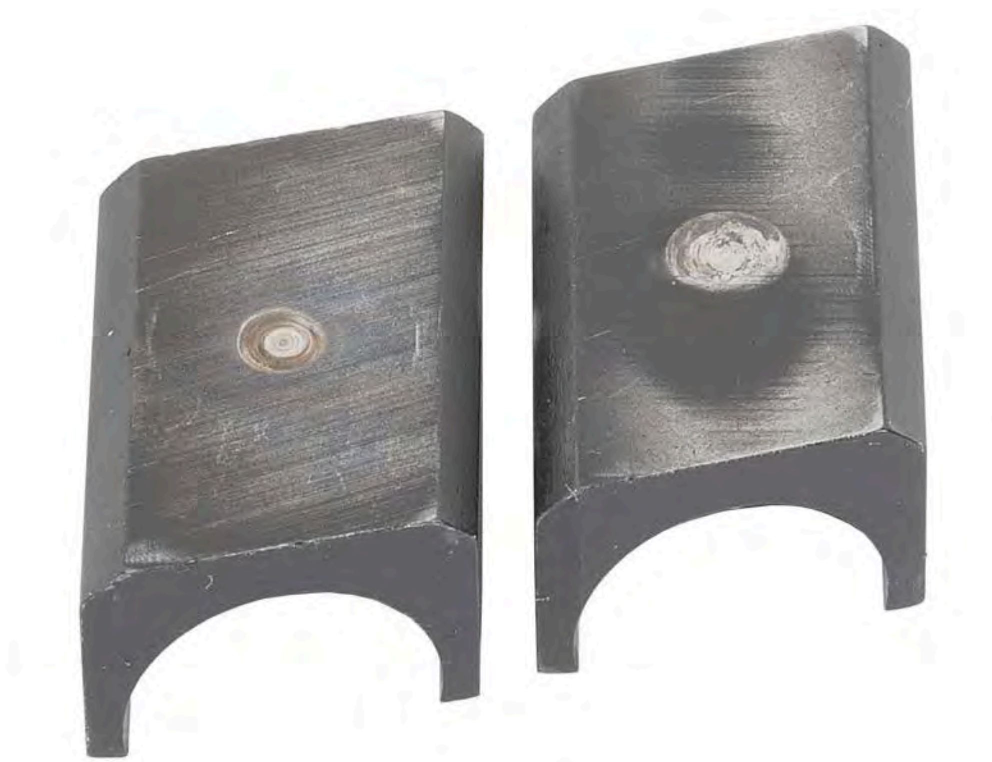
SN15396950 Shoes (Front), Before



SN15396950 Shoes (Front), After



SN15396950 Shoes (Back), Before



SN15396950 Shoes (Back), After

SN15396950 Rollers, Before

SN15396950 Rollers, After

SN15396950 Piston Plungers, Before

SN15396950 Piston Plungers, After

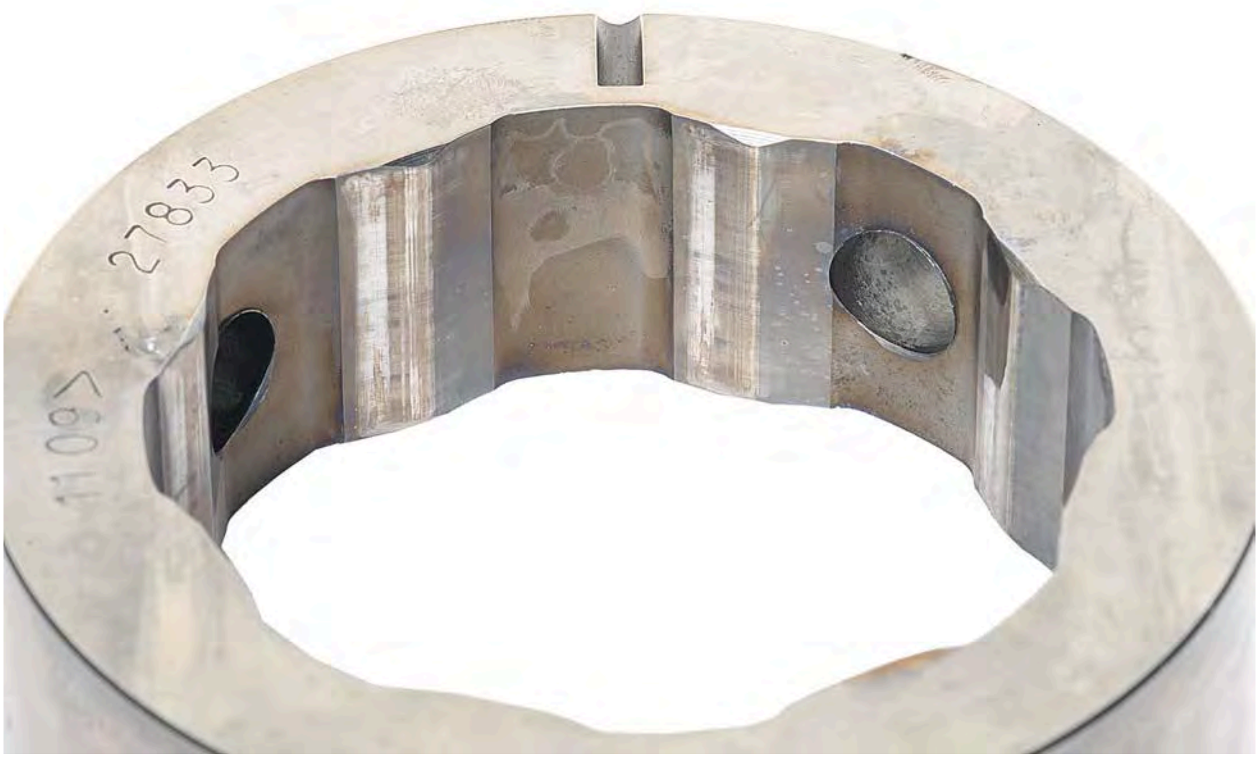
SN15396950 Thrust Washer, Before

SN15396950 Thrust Washer, After

SN15396950 Governor Weight, Before

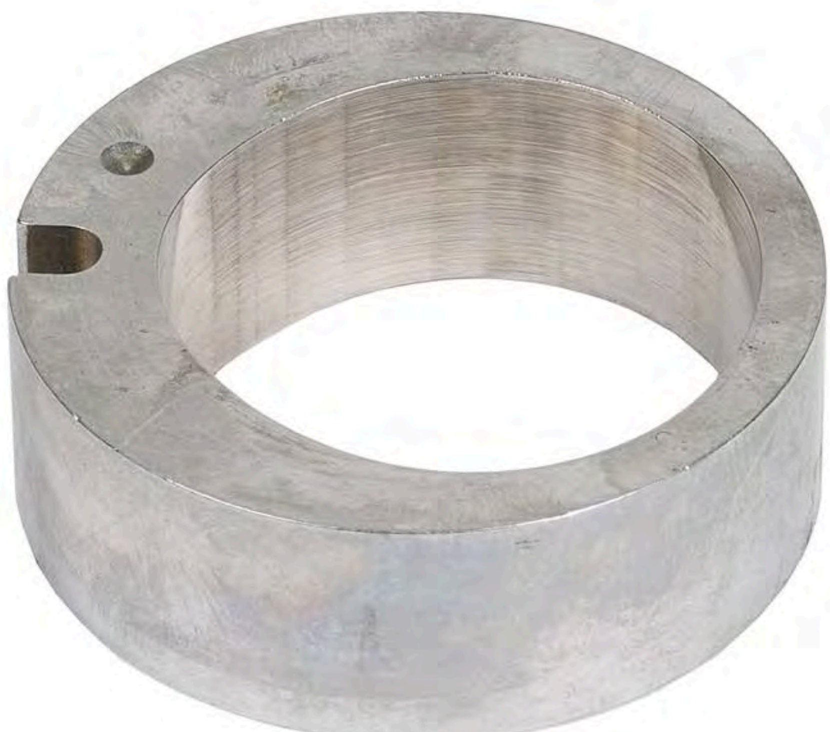
SN15396950 Governor Weight, After

SN15396950 Cam Ring, Before



SN15396950 Cam Ring, After

SN15396950 Eccentric Ring, Before



SN15396950 Eccentric Ring, After

SN1596950 Rotor (Front), Before

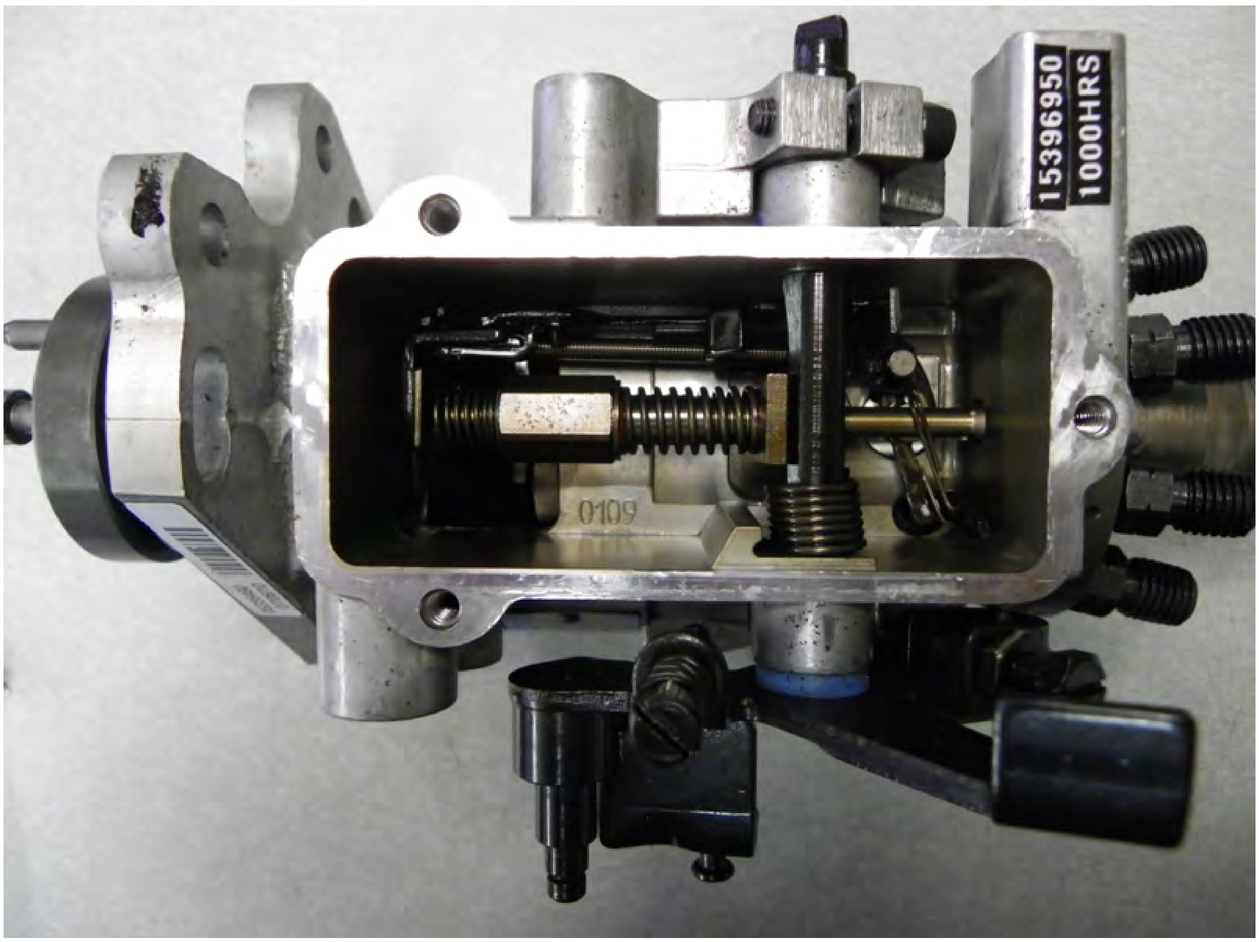
SN1596950 Rotor (Front), After

SN15396950 Rotor (Back), Before

SN15396950 Rotor (Back), After

SN15396950 Drive Tang, Before

SN15396950 Drive Tang, After



SN15396950 Governor Assembly

APPENDIX H

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 22.5-mg/L DCI-4A
Test Number: C3T8-57-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 22.5-mg/L DCI-4A

Test Fuel ID: AF7090

Test Temperature: 57°C (135°F)

Test Number: C3T8-57-1000

Start of Test Date: March 31, 2011

End of Test Date: June 03, 2011

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure H-1.

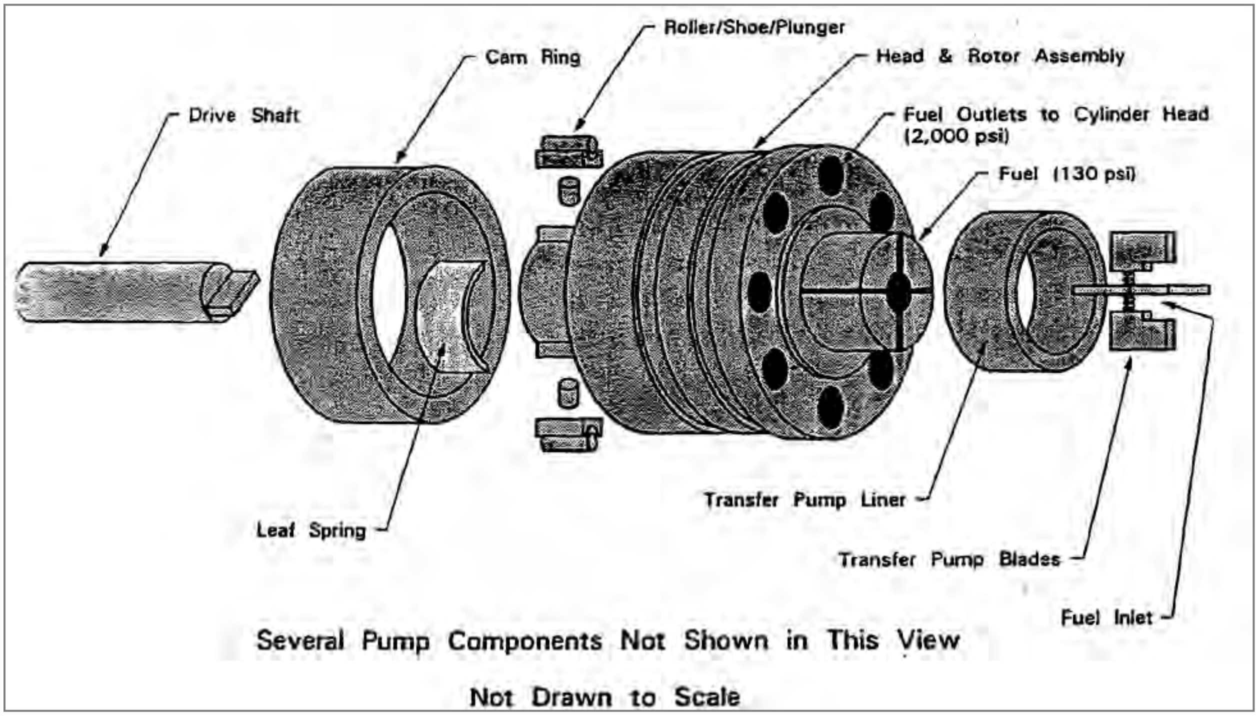


Figure H-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table H-1.

Table H-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	57 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table H-2.

Table H-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.04
FLO_R	Injected Flow-rate [mL/min]	755.5	14.6
FUELIN_P	Fuel Inlet Pressure [psig]	2.8	0.29
TRNS_P_R	Transfer Pump Pressure [psig]	67.7	1.5
HSG_P_R	Pump Housing Pressure [psig]	12.4	0.82
RTRN_T_R	Fuel Return Temperature [°C]	63.6	1.18
FUEL_T	Fuel Tank Temperature [°C]	30.2	2.67
FUELIN_T	Fuel Inlet Temperature [°C]	57	0.47

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure H-2 through Figure H-4.

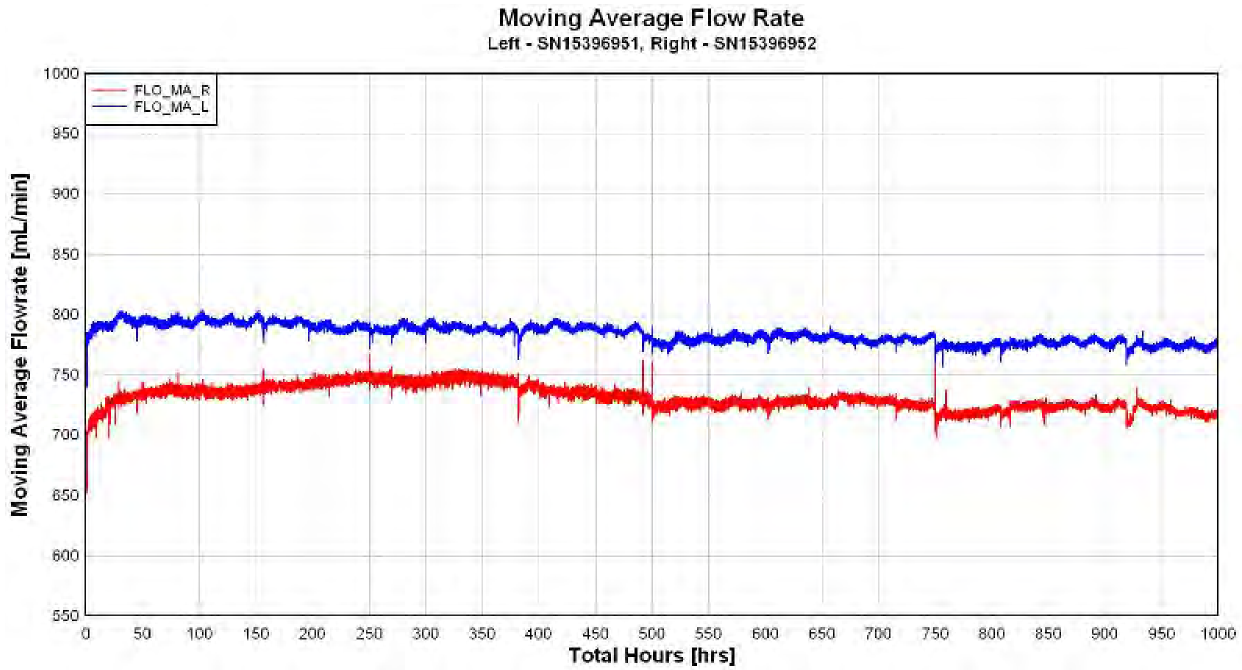


Figure H-2. Pump Flow, Moving Average

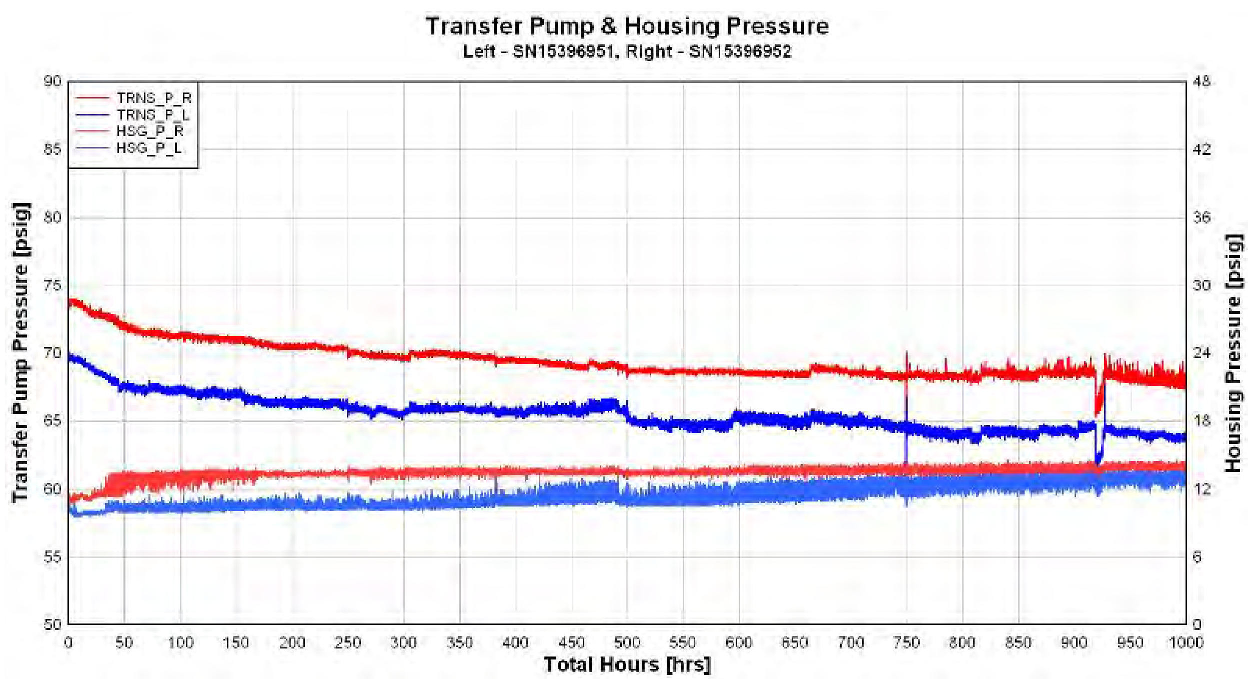


Figure H-3. Transfer Pump & Housing Pressure

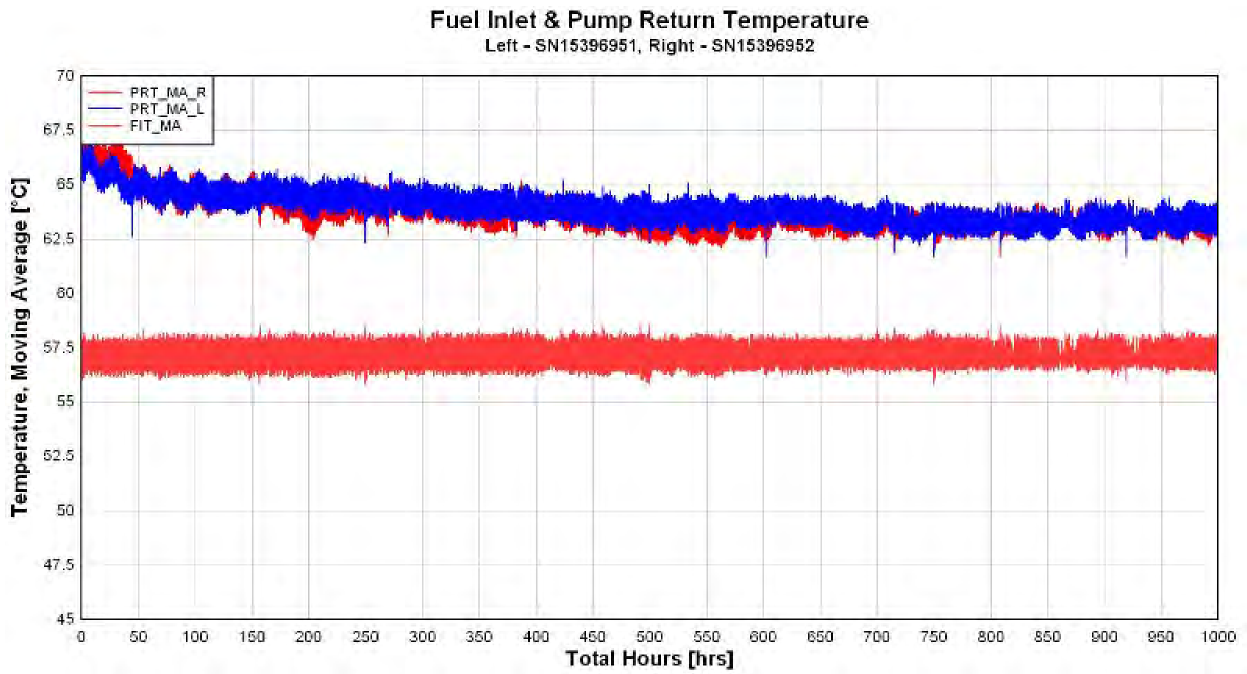


Figure H-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table H-3. (Note – Calibration data to be used as reference only).

Table H-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 8			Test Duration : 1000-hrs.		
Test Fuel : Jet A-1 with 22.5-mg/L DCI-4A @ 135°F				SN : 15396951			SN : 15396952		
PUMP RPM	Description	Specification		Pump Duration : 1000.-hrs.			Pump Duration : 1000.-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	62 psi	psi	61 psi	**63 psi**	-2 psi
	Return Fuel	225 cc	375 cc	320 cc	350 cc	-30 cc	360 cc	372 cc	-12 cc
350	Low Idle	12 cc	16 cc	15 cc	**10 cc**	5 cc	15 cc	**8 cc**	7 cc
	Housing psi.	8 psi	12 psi	**4.7 psi**	9.0 psi	-4.4 psi	9.5 psi	10.0 psi	-.5 psi
	Advance	3.50°		4.65°	4.53°	.12°	4.20°	**3.20°**	1.00°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	**65.0 cc**	3.0 cc	68.0 cc	**65.0 cc**	3.0 cc
1600	WOT Fuel delivery	60 cc		66 cc	64 cc	2 cc	65 cc	62 cc	3 cc
	WOT Advance	2.50°	3.50°	2.99°	3.06°	-.07°	3.01°	2.80°	.21°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	23.0 cc	-1.0 cc
	Face Cam Advance	5.25°	7.25°	6.76°	6.30°	.46°	6.30°	5.48°	.82°
	Low Idle	11.0°	12.0°	11.3°	11.4°	.0°	11.2°	**10.9°**	.3°
1825	Fuel Delivery	33 cc		38 cc	58 cc	-20 cc	39 cc	48 cc	-9 cc
1950	High Idle		15 cc	1 cc	2 cc	-1 cc	2 cc	2 cc	cc
	Transfer pump psi.		125 psi	103 psi	105 psi	-2 psi	99 psi	107 psi	-8 psi
200	WOT Fuel Delivery	58 cc		62 cc	**56 cc**	6 cc	63 cc	60 cc	3 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		50 cc	44 cc	6 cc	54 cc	49 cc	5 cc
	Transfer pump psi.	16 psi		29 psi	**8 psi**	21 psi	25 psi	25 psi	0 psi
	Housing psi.	.0 psi	12 psi	8.0 psi	8 psi	1 psi	8 psi	9 psi	-1 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	.00°	-.50°	.50°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table H-4 and Table H-5.

Table H-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396951	Test Number: 8	
Fuel Description : Jet A-1 with 22.5-mg/L DCI-4A @ 135°F				
	Date:	1/0/1900	8/29/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2324	3.2312	-0.0012
Measurement 2		3.2325	3.2312	-0.0013
Measurement 3		3.2324	3.2313	-0.0011
Measurement 4		3.2324	3.2313	-0.0011
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2537	3.2546	0.0009
Measurement 2		3.2540	3.2545	0.0005
Measurement 3		3.2537	3.2545	0.0008
Measurement 4		3.2538	3.2544	0.0006
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2459	3.2454	-0.0005
Measurement 2		3.2460	3.2454	-0.0006
Measurement 3		3.2459	3.2452	-0.0007
Measurement 4		3.2460	3.2453	-0.0007
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2319	3.2303	-0.0016
Measurement 2		3.2320	3.2302	-0.0018
Measurement 3		3.2317	3.2303	-0.0014
Measurement 4		3.2318	3.2303	-0.0015
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2324	3.2313	-0.0012
Transfer Pump Blade 2		3.2538	3.2545	0.0007
Transfer Pump Blade 3		3.2460	3.2453	-0.0006
Transfer Pump Blade 4		3.2319	3.2303	-0.0016
	Roller to Roller (in)	1.9760	1.9753	-0.0007
	Eccentricity (in.)	0.0130	0.0140	0.0010
	Drive Backlash (In)	0.0050	0.0070	0.0020

Table H-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)	SN: 15396952	Test Number: 8
Fuel Description : Jet A-1 with 22.5-mg/L DCI-4A @ 135°F		

	Date:	1/0/1900	9/8/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2533	3.2487	-0.0046
Measurement 2		3.2533	3.2487	-0.0046
Measurement 3		3.2532	3.2486	-0.0046
Measurement 4		3.2533	3.2486	-0.0047
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2635	3.2603	-0.0032
Measurement 2		3.2634	3.2602	-0.0032
Measurement 3		3.2635	3.2601	-0.0034
Measurement 4		3.2635	3.2600	-0.0035
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2424	3.2413	-0.0011
Measurement 2		3.2425	3.2414	-0.0011
Measurement 3		3.2424	3.2414	-0.0010
Measurement 4		3.2424	3.2414	-0.0010
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2683	3.2646	-0.0037
Measurement 2		3.2683	3.2646	-0.0037
Measurement 3		3.2683	3.2646	-0.0037
Measurement 4		3.2682	3.2346	-0.0336
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2533	3.2487	-0.0046
Transfer Pump Blade 2		3.2635	3.2602	-0.0033
Transfer Pump Blade 3		3.2424	3.2414	-0.0010
Transfer Pump Blade 4		3.2683	3.2571	-0.0112
	Roller to Roller (in)	1.9760	1.9750	-0.0010
	Eccentricity (in.)	0.0080	0.0100	0.0020
Note: Stained brown	Drive Backlash (In)	0.0030	0.0050	0.0020

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table H-6.

Table H-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation
6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
8	15396951	Jet A-1 with 22.5-mg/L DCI-4A @ 135°F	8-1	2150	1850	Pass	Pass	Pass	Pass	Pass	Pass
			8-2	2150	1750	Pass	Pass	Pass	Pass	Pass	Pass
			8-3	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			8-4	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			8-5	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			8-6	2100	1800	Pass	Pass	Pass	Pass	Pass	Pass
			8-7	2200	1850	Pass	Pass	Pass	Pass	Pass	Pass
			8-8	2150	1850	Pass	Pass	Pass	Pass	Pass	Pass
8	15396952	Jet A-1 with 22.5-mg/L DCI-4A @ 135°F	8-11	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			8-12	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			8-13	2075	1850	Pass	Pass	Pass	Pass	Pass	Pass
			8-14	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			8-15	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			8-16	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			8-17	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			8-18	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table H-7 and Table H-8.

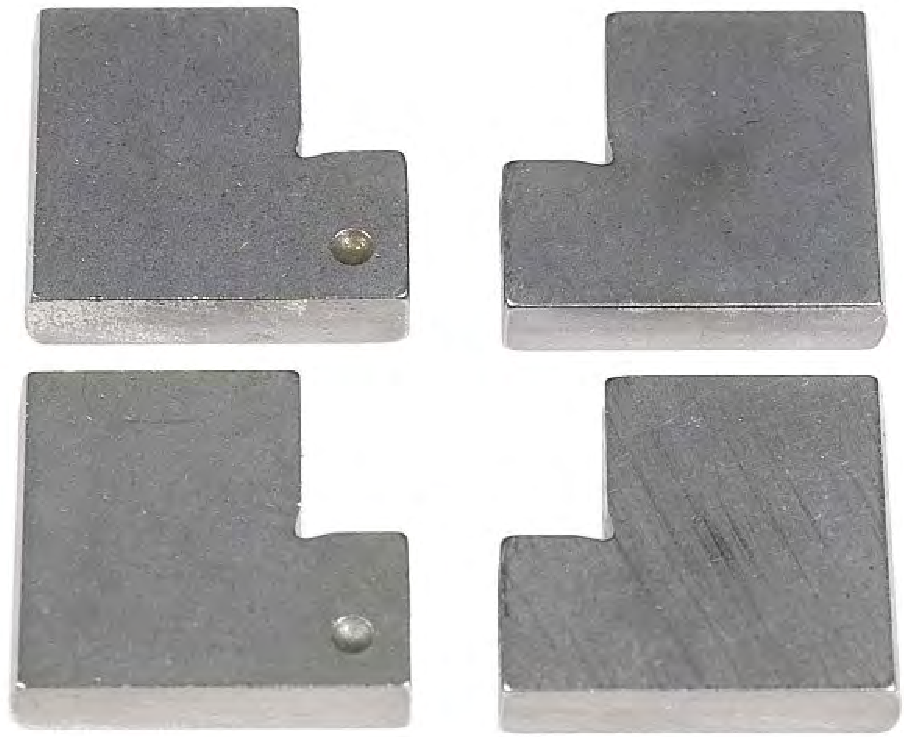
Table H-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079 (arctic)		SN: 15396951
Test Condition : Jet A-1 with 22.5-mg/L DCI-4A @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	No wear	0
LINER	Scarring wear on 80% of surface	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Polishing wear in various spots	1.5
ROTOR	Light wear lines in various spots	1.5
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear in various spots	1.5
PLUNGERS	Polishing wear at end of oposite shoes	1.5
SHOES	Dimple on back, light wear marks from leaf spring	1.5
ROLLERS	No wear, but dark lines showing	1
LEAF SPRING	Light wear from roller contact	1
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Wear from weight contact. Slight groove	1.5
THRUST SLEEVE	Light wear from governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact T washer	1.5
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Scarring wear top right and lower left	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.370

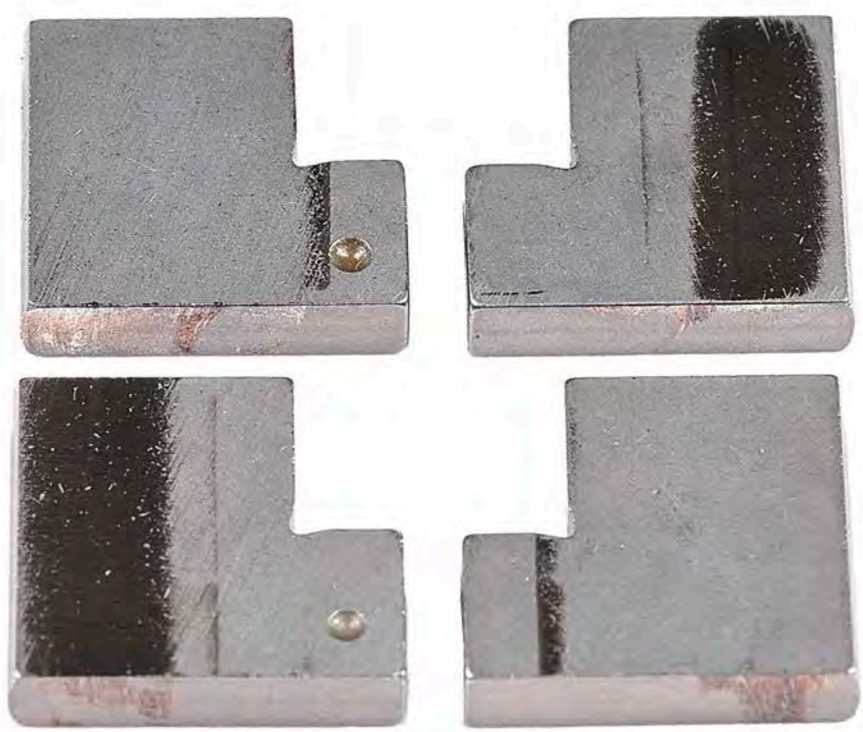
Table H-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079 (arctic)		SN: 15396952
Test Condition : Jet A-1 with 22.5-mg/L DCI-4A @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing Wear	1
LINER	Scarring wear on 80% of surface	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Polishing wear in various spots	1.5
ROTOR	Light wear around distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear	1.5
PLUNGERS	Left-medium polishing wear; right-discloration	2
SHOES	Dimple on back, light wear marks from leaf spring, scorring from rollers	2
ROLLERS	No wear, but dark lines showing and light pitting	1.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Light pitting from rollers	2
THRUST WASHER	Wear from weight contact. Slight groove	1.5
THRUST SLEEVE	Light wear from governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact T washer	1.5
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Scarring wear top right and lower left	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.587

PHOTOGRAPHS FOR LEFT PUMP



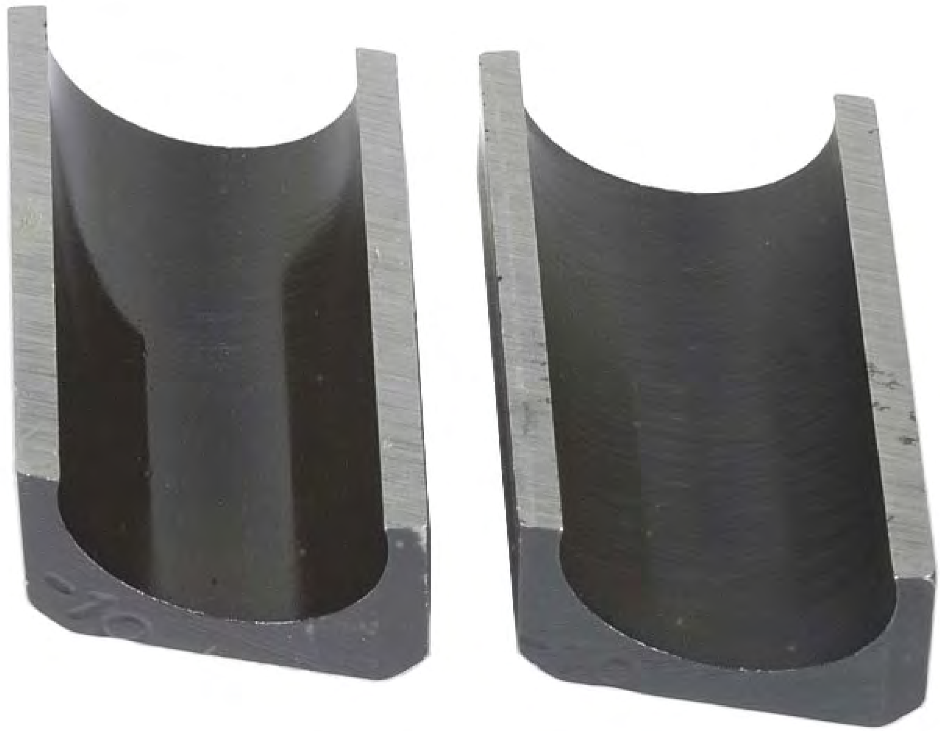
SN15396951 Transfer Pump Blades (Side), Before



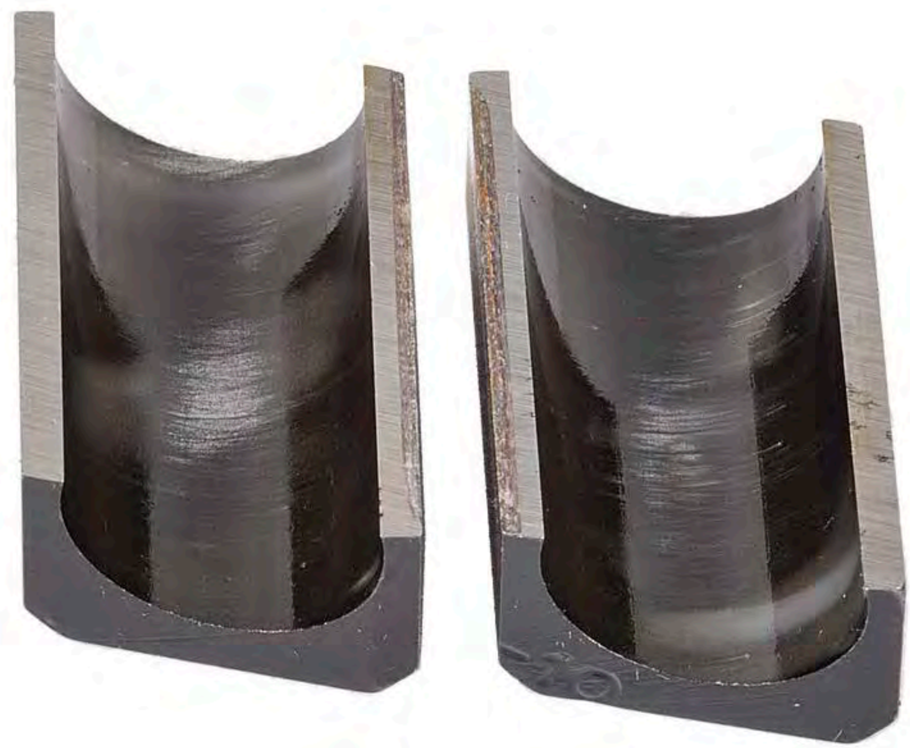
SN15396951 Transfer Pump Blades (Side), After

SN15396951 Transfer Pump Blades (Profile), Before

SN15396951 Transfer Pump Blades (Profile), After



SN15396951 Shoes (Front), Before



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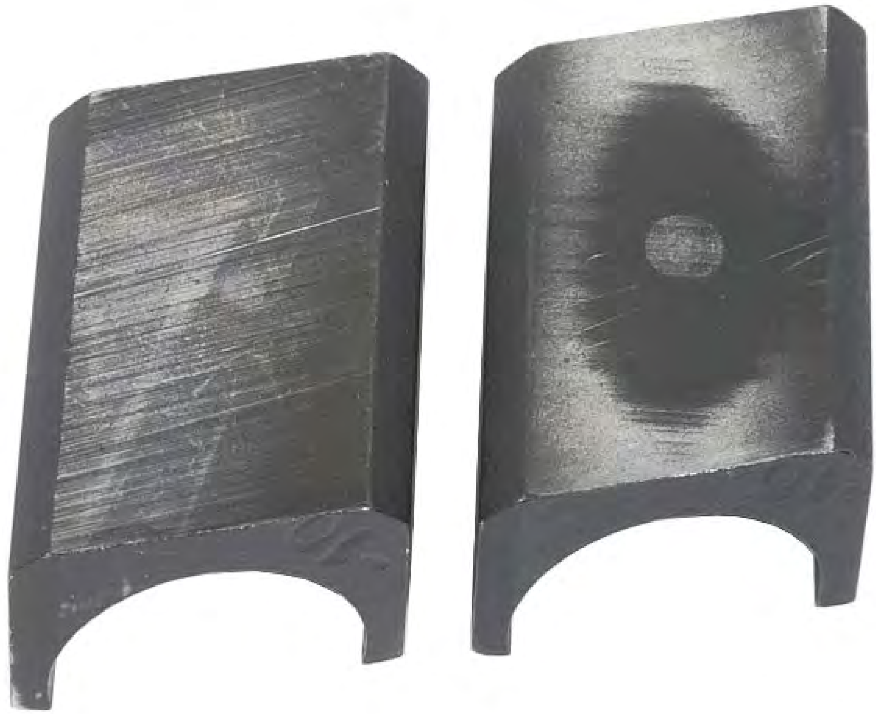

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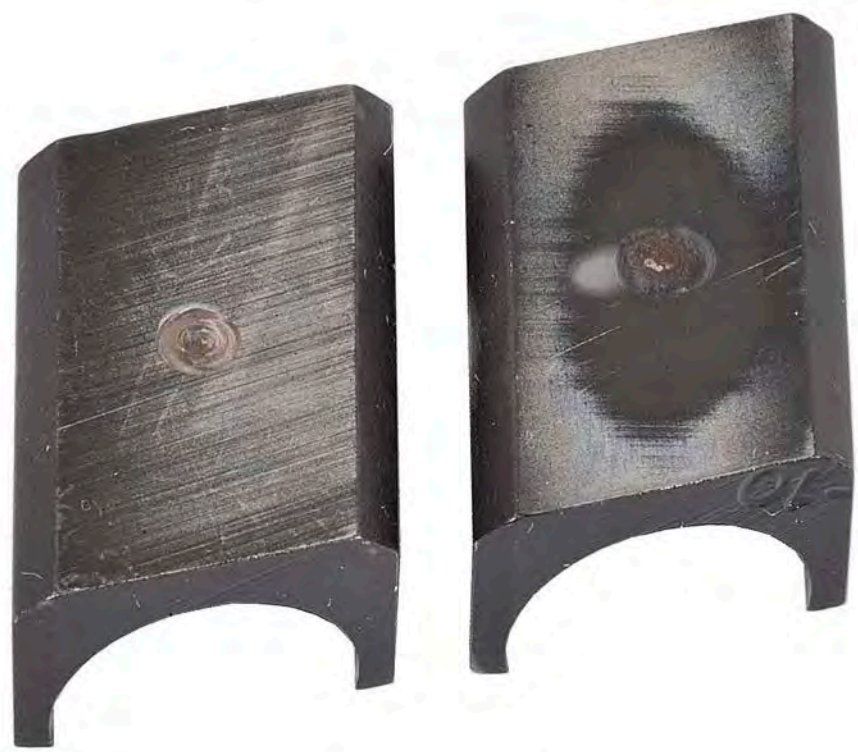


SN15396951 Shoes (Back), After

SN15396951 Rollers, Before

SN15396951 Rollers, After

SN15396951 Piston Plungers, Before

SN15396951 Piston Plungers, After

SN15396951 Thrust Washer, Before

SN15396951 Thrust Washer, After

SN15396951 Governor Weight, Before

SN15396951 Governor Weight, After

SN15396951 Cam Ring, Before

SN15396951 Cam Ring, After

SN15396951 Eccentric Ring, Before

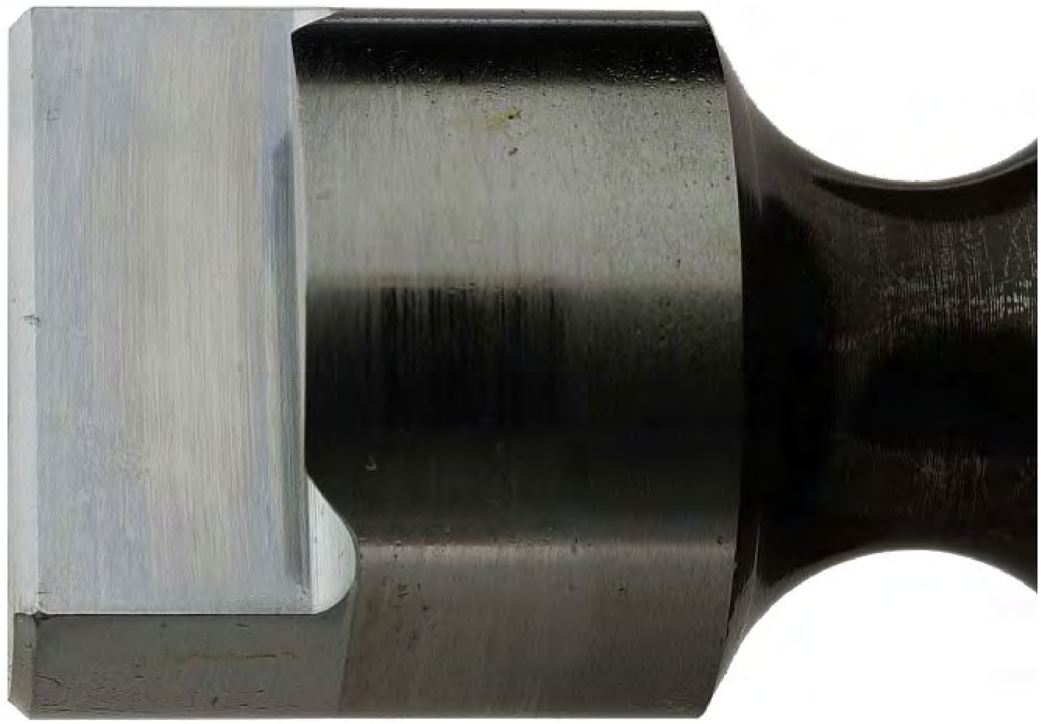
SN15396951 Eccentric Ring, After

SN15396951 Rotor (Front), Before

SN15396951 Rotor (Front), After

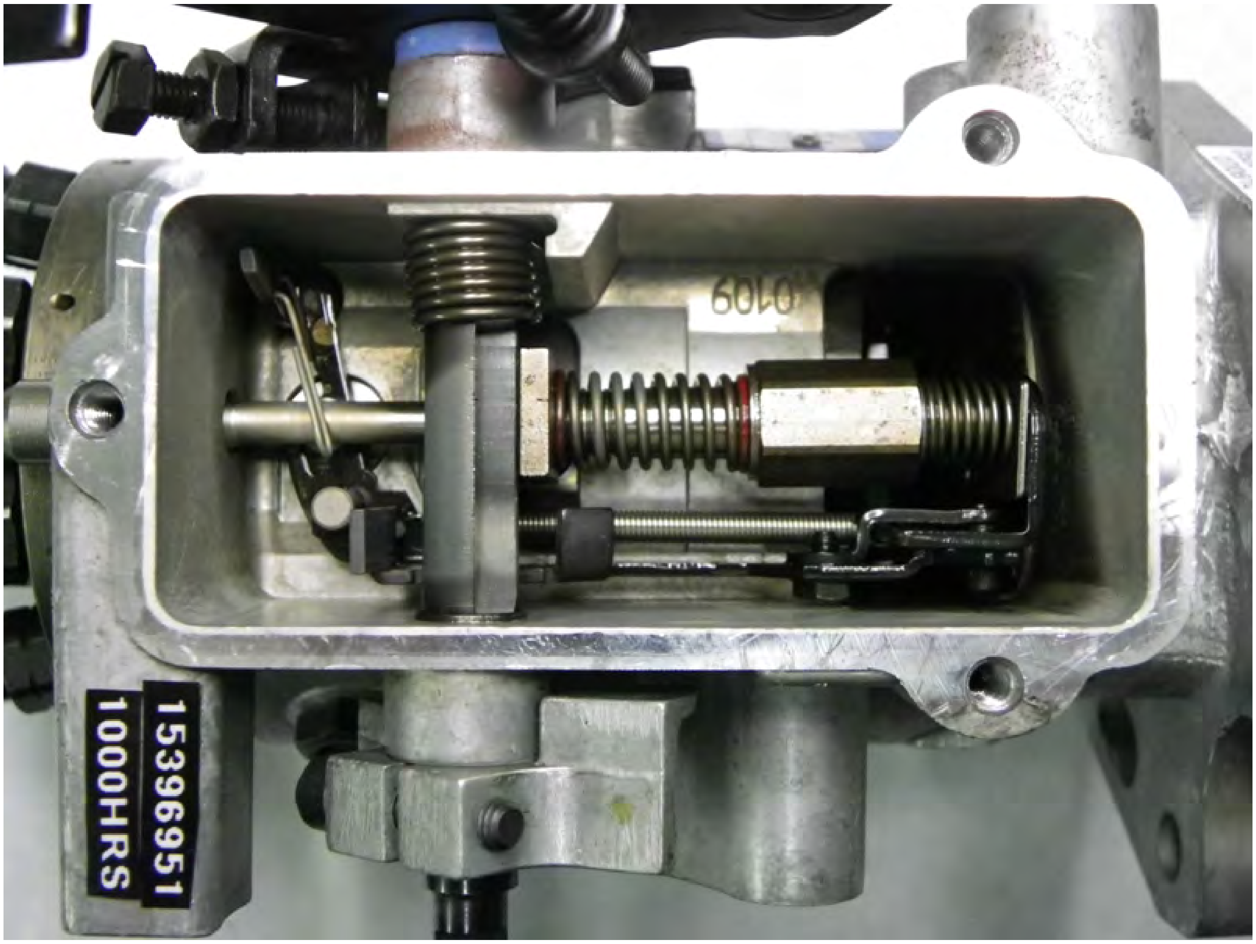
SN15396951 Rotor (Back), Before

SN15396951 Rotor (Back), After



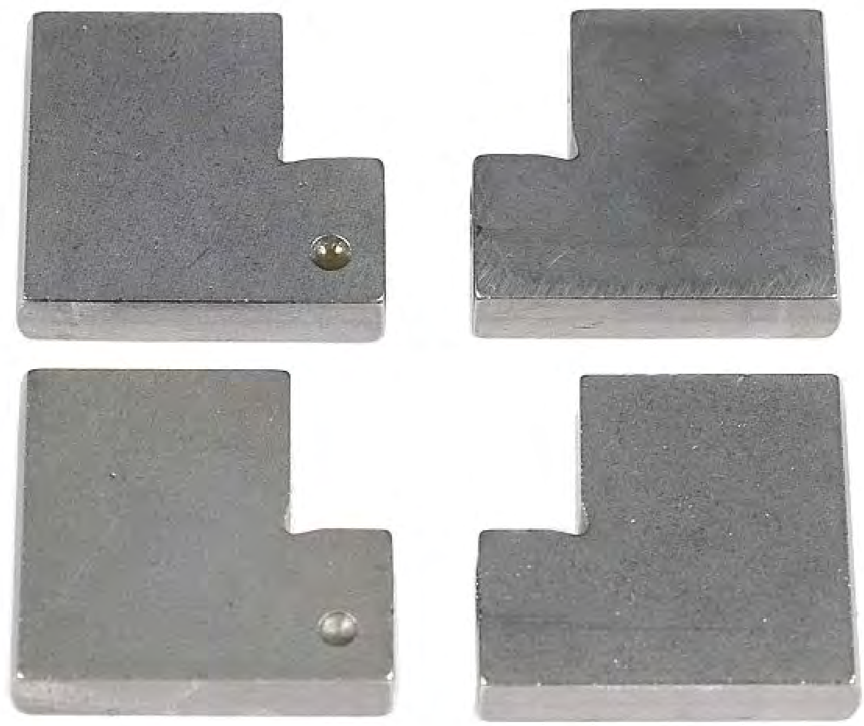
SN15396951 Drive Tang, Before

SN15396951 Drive Tang, After

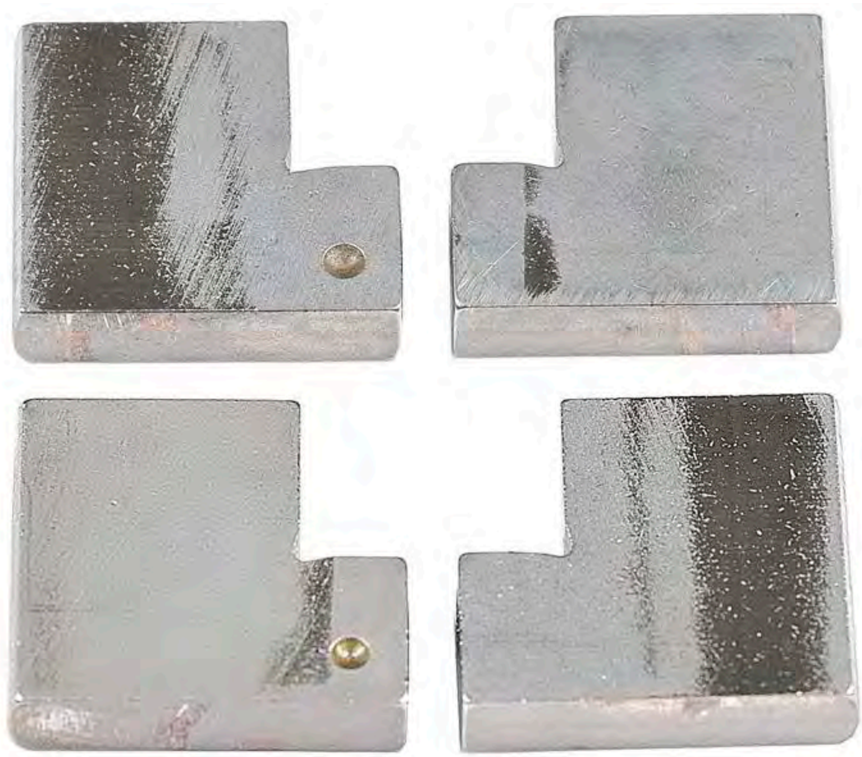


SN15396951 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



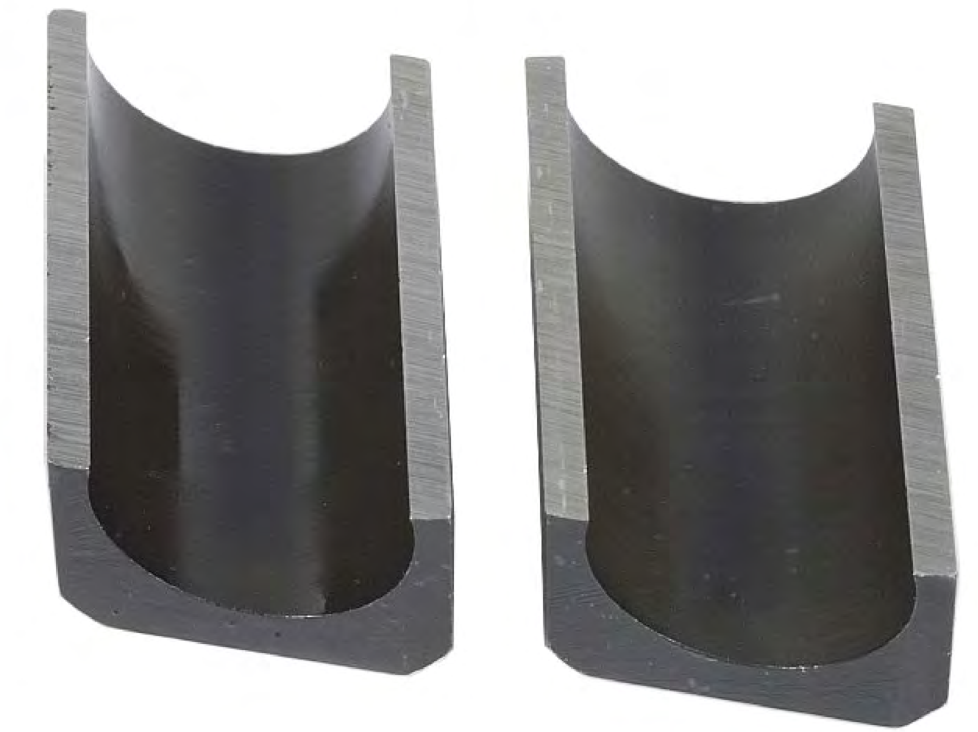
SN15396952 Transfer Pump Blades, Before



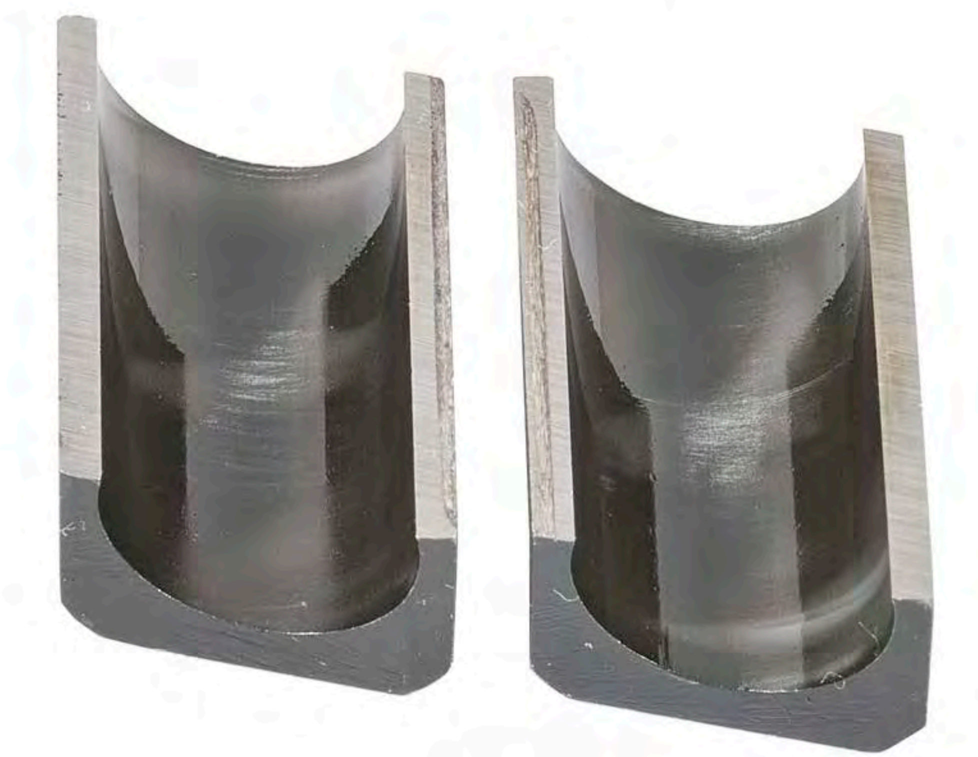
SN15396952 Transfer Pump Blades, After

SN15396952 Transfer Pump Blades (Profile), Before

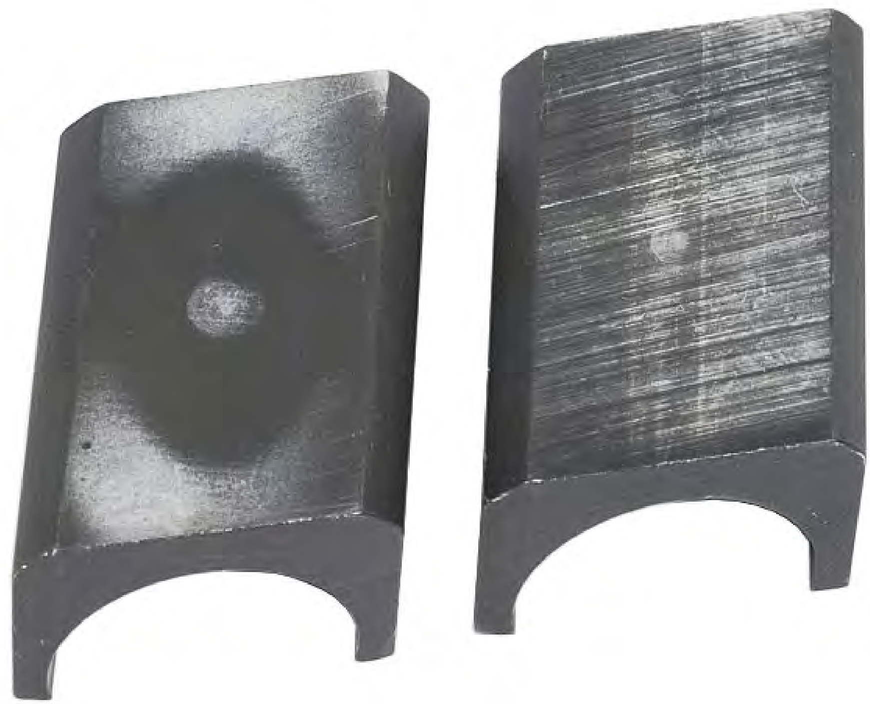
SN15396952 Transfer Pump Blades (Profile), After



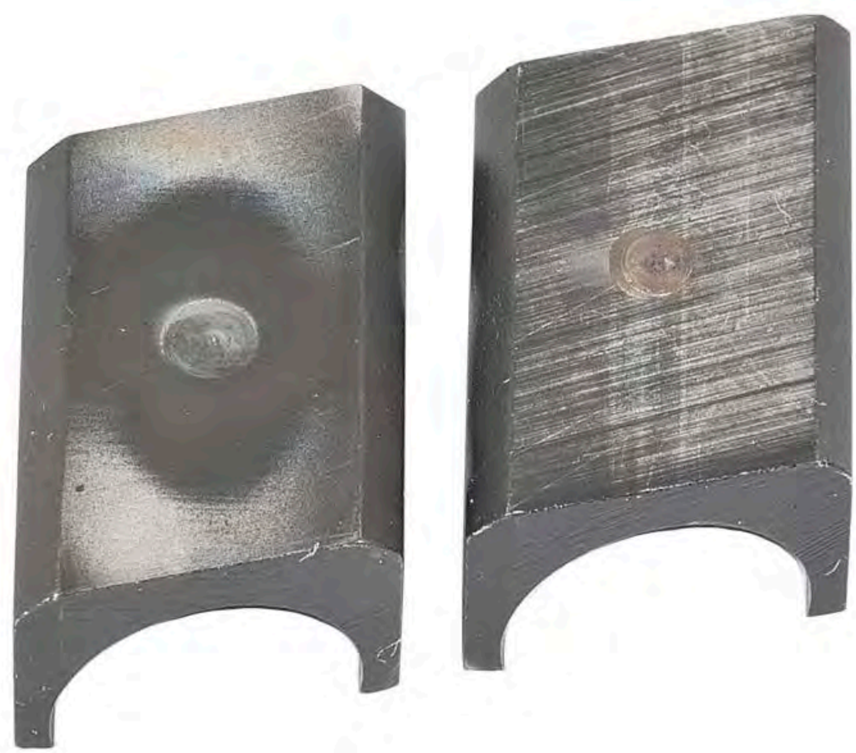
SN15396952 Shoes (Front), Before



SN15396952 Shoes (Front), After



SN15396952 Shoes (Back), Before



SN15396952 Shoes (Back), After

SN15396952 Rollers, Before

SN15396952 Rollers, After

SN15396952 Piston Plungers, Before

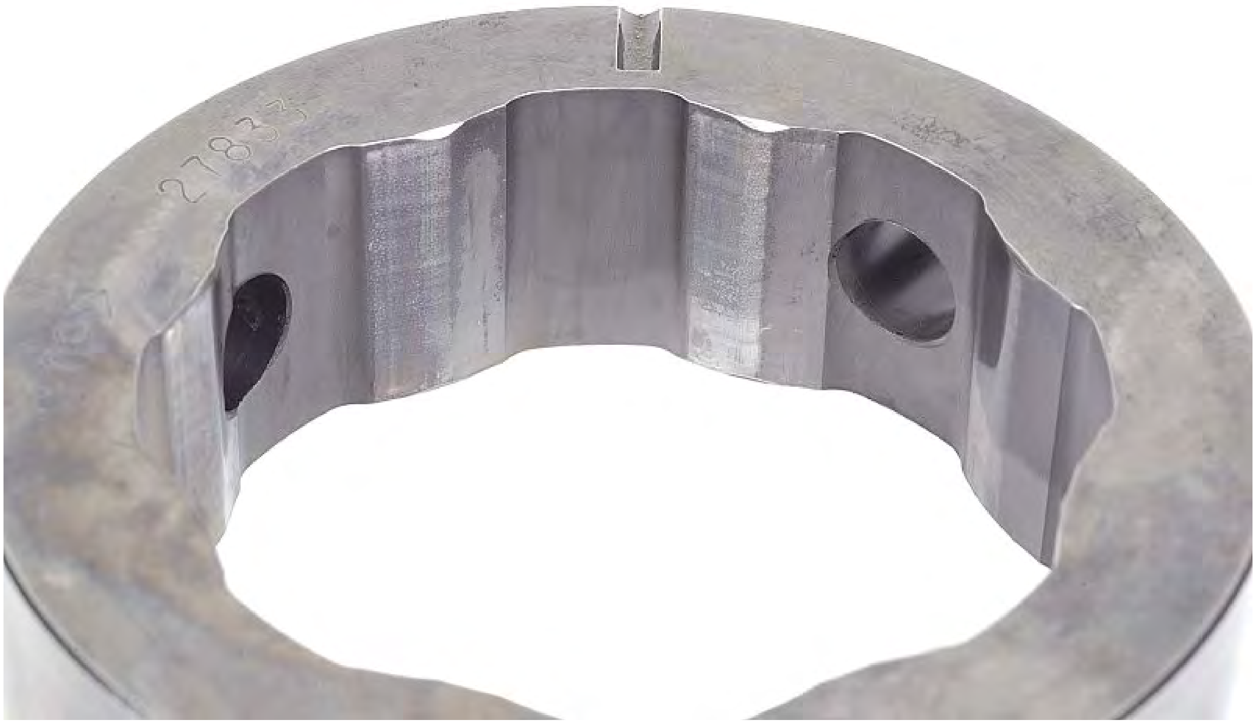
SN15396952 Piston Plungers, After

SN15396952 Thrust Washer, Before

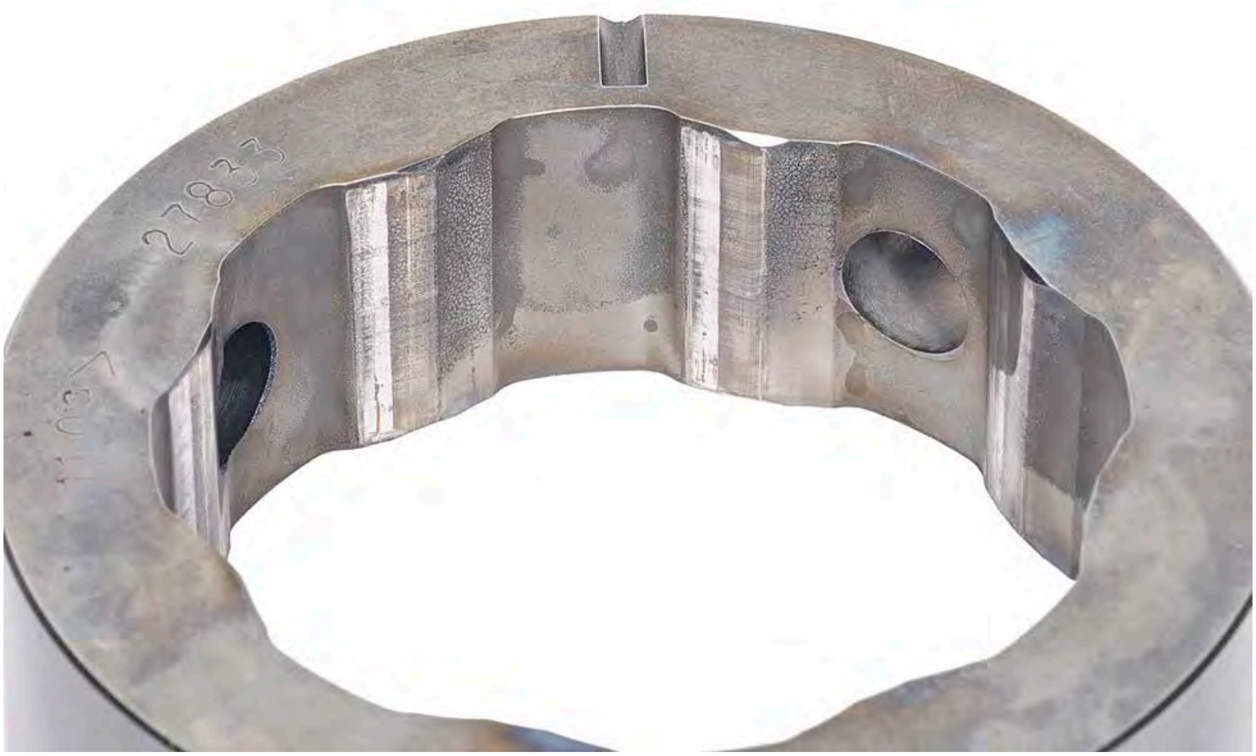
SN15396952 Thrust Washer, After

SN15396952 Governor Weight, Before

SN15396952 Governor Weight, After



SN15396952 Cam Ring, Before



SN15396952 Cam Ring, After

SN15396952 Eccentric Ring, Before

SN15396952 Eccentric Ring, After

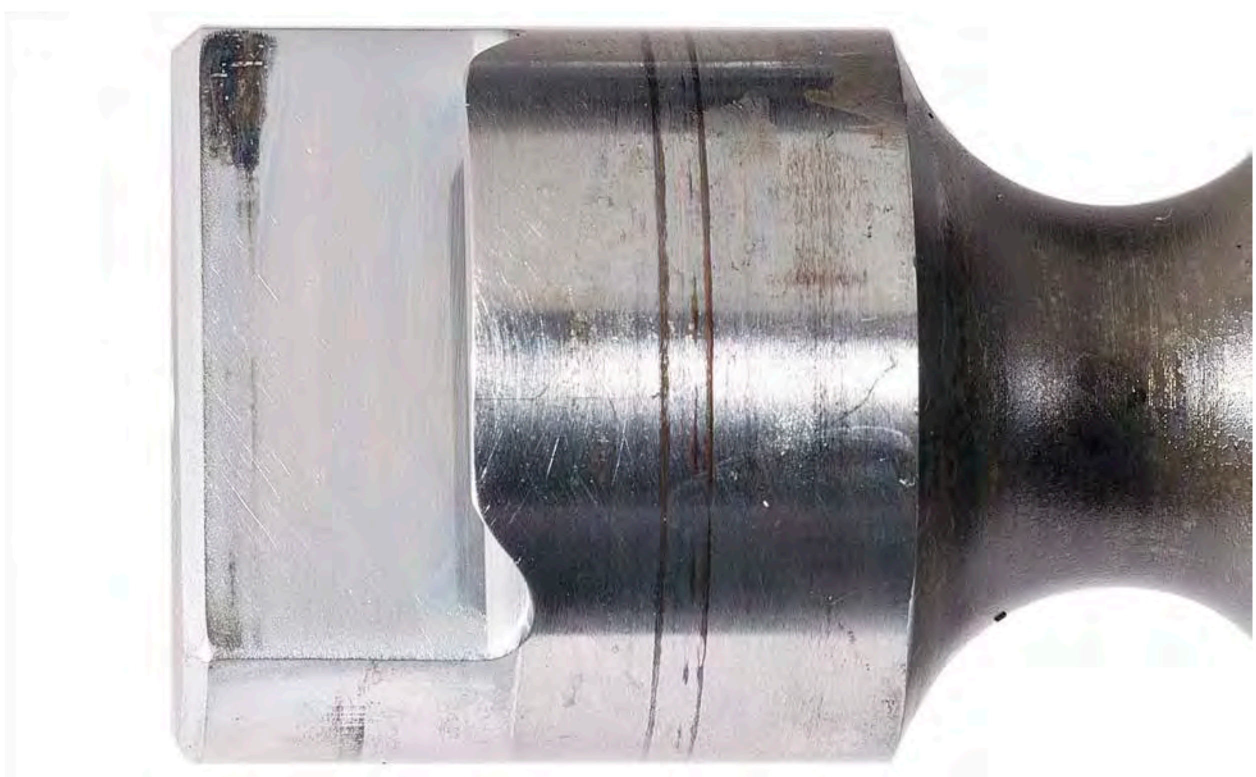
SN1596952 Rotor (Front), Before

SN1596952 Rotor (Front), After

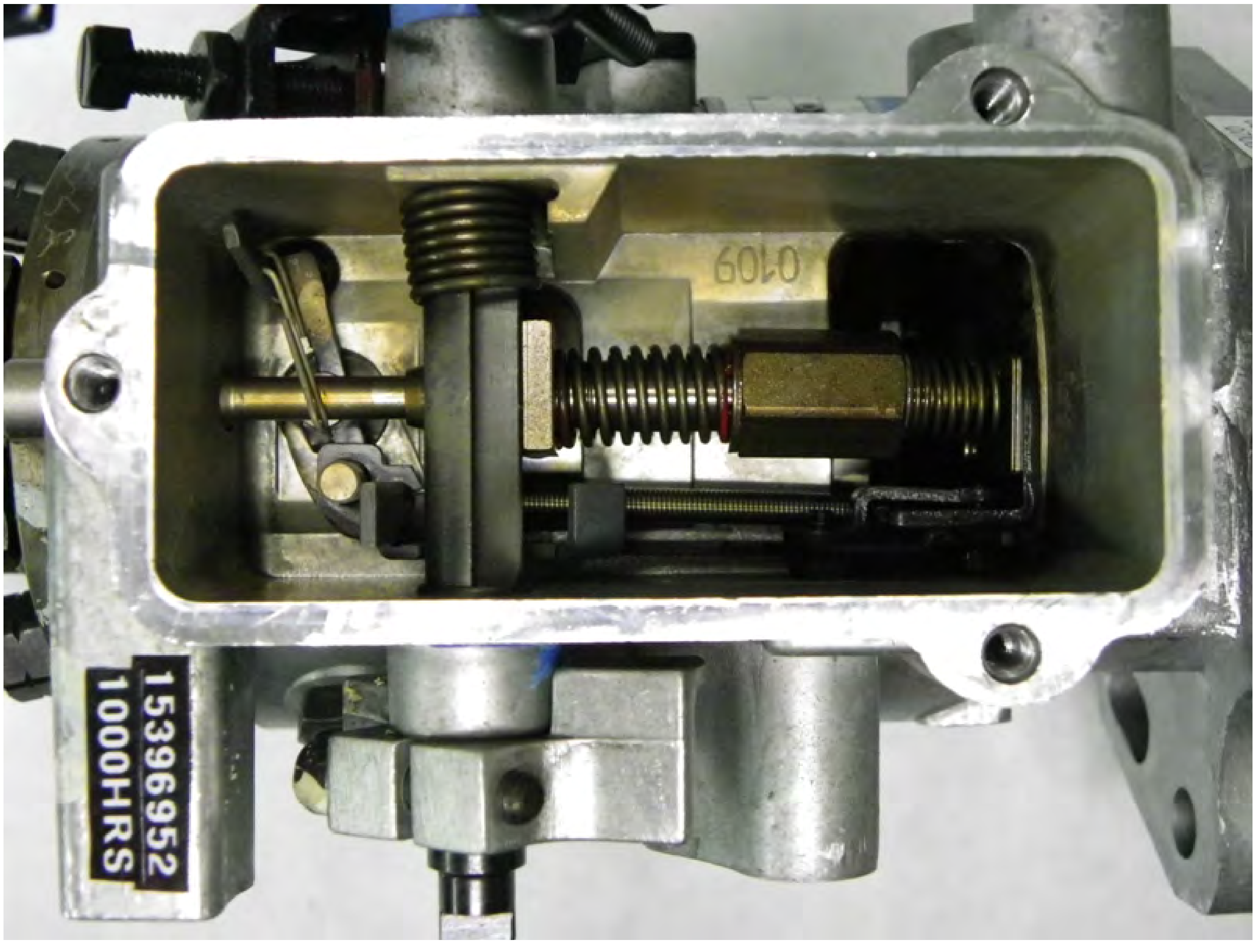
SN15396952 Rotor (Back), Before

SN15396952 Rotor (Back), After

SN15396952 Drive Tang, Before



SN15396952 Drive Tang, After



SN15396952 Governor Assembly

SN15396952 Transfer Pump Regulator Assembly

APPENDIX I

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 25-mg/L Nalco 5403
Test Number: C4T9-57-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 25-mg/L Nalco 5403

Test Fuel ID: AF7090

Test Temperature: 57°C (135°F)

Test Number: C4T9-57-1000

Start of Test Date: April 11, 2011

End of Test Date: June 17, 2011

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure I-1.

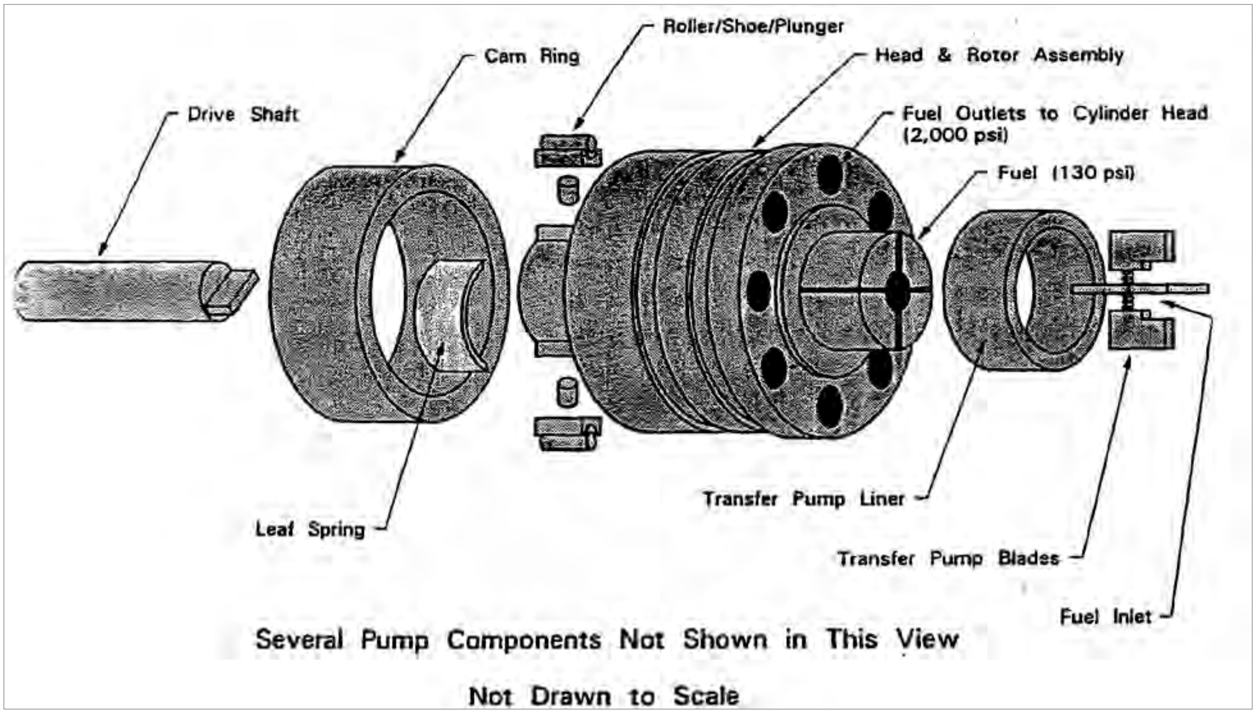


Figure I-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table I-1.

Table I-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	57 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table I-2.

Table I-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1701	2.4
FLO_R	Injected Flow-rate [mL/min]	620.8	33.5
FUELIN_P	Fuel Inlet Pressure [psig]	2.8	0.2
TRNS_P_R	Transfer Pump Pressure [psig]	74	0.56
HSG_P_R	Pump Housing Pressure [psig]	11.6	0.58
RTRN_T_R	Fuel Return Temperature [°C]	64.3	.60
FUEL_T	Fuel Tank Temperature [°C]	27.1	1.6
FUELIN_T	Fuel Inlet Temperature [°C]	57.0	0.12

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure I-2 through Figure I-4.

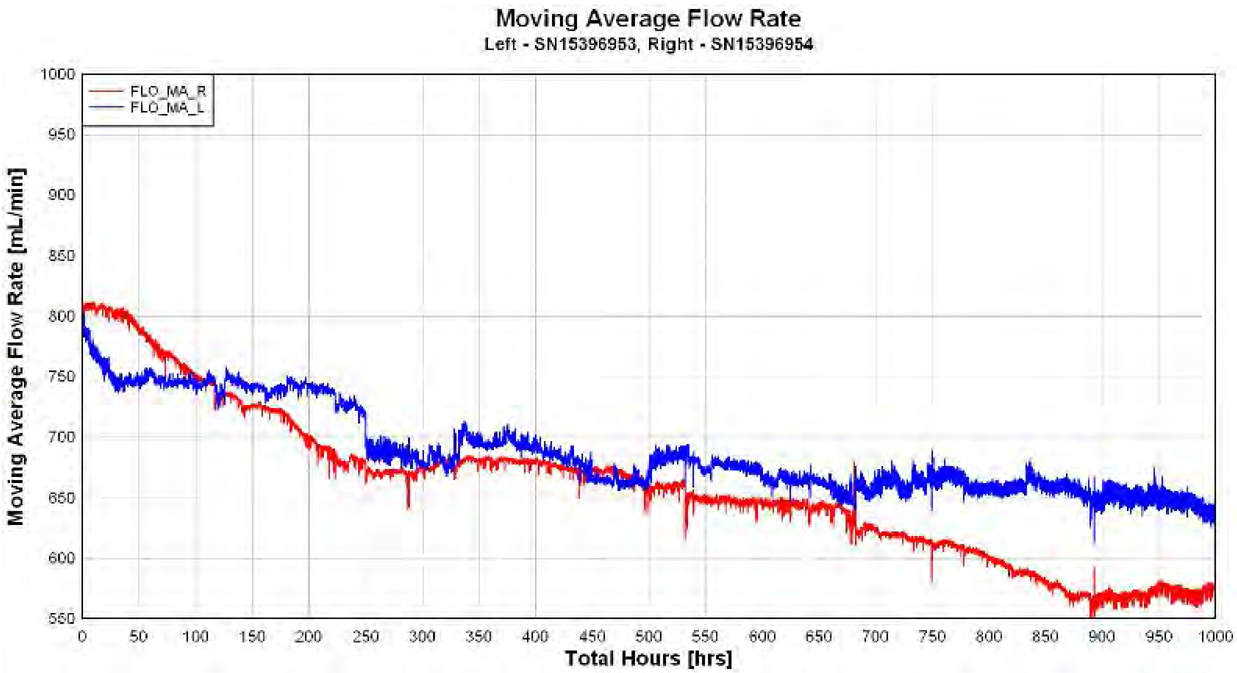


Figure I-2. Pump Flow, Moving Average

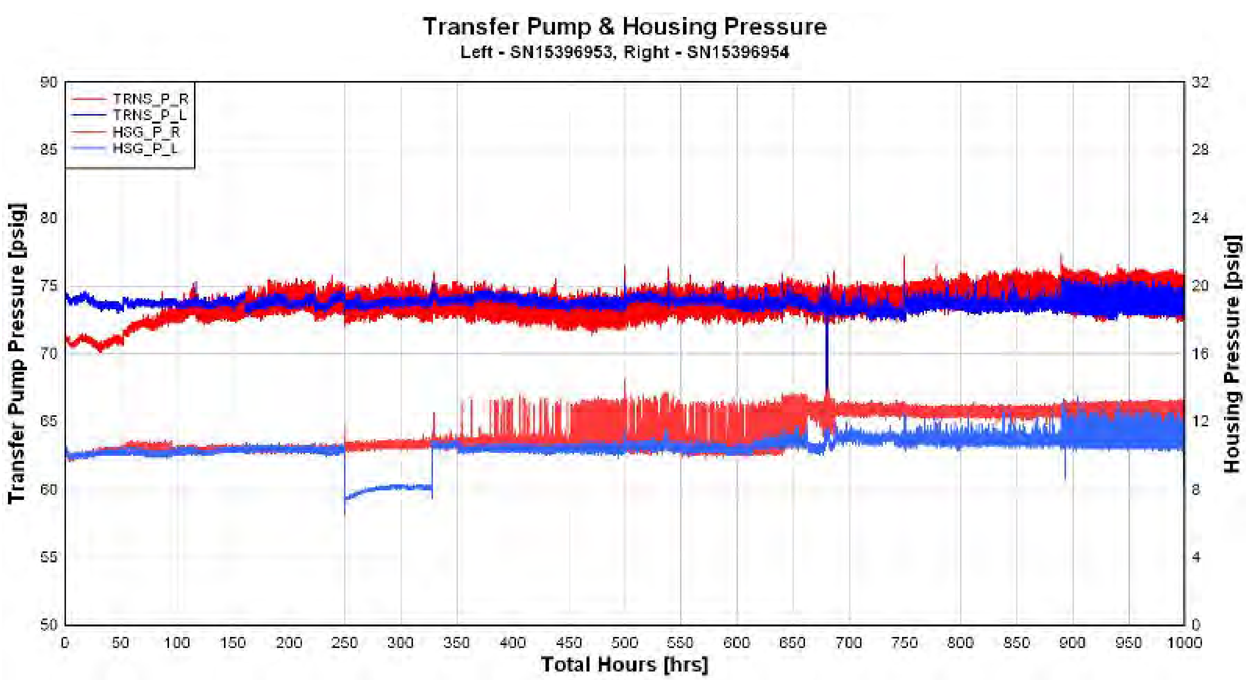


Figure I-3. Transfer Pump & Housing Pressure

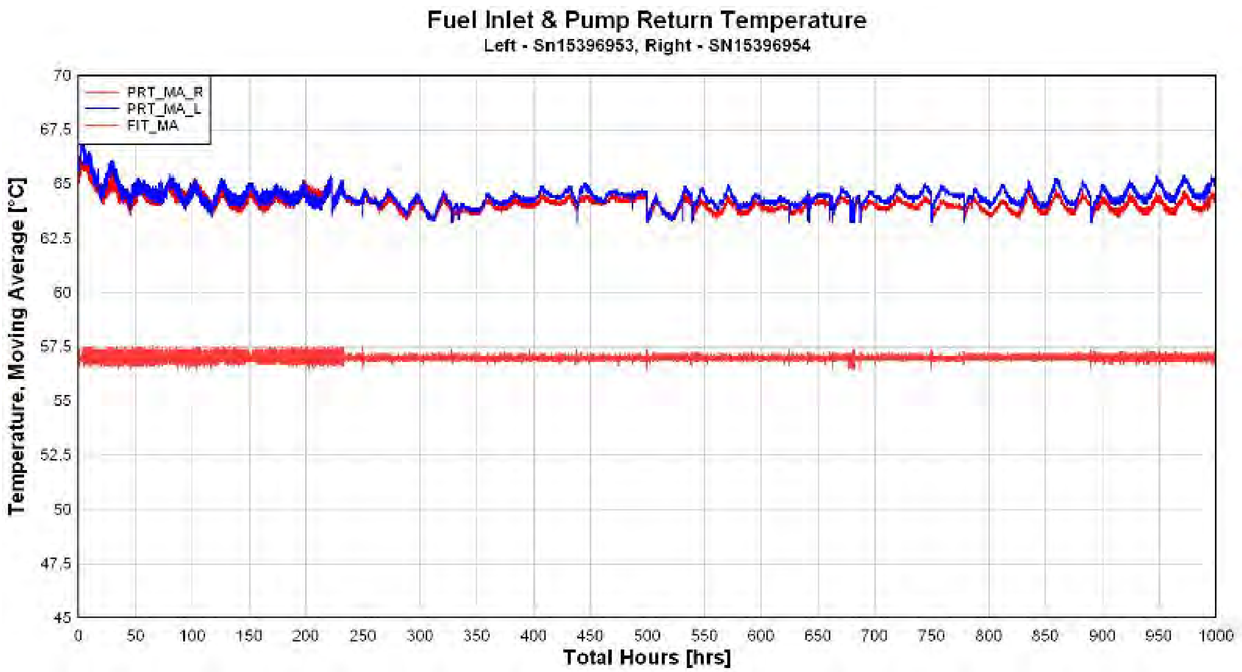


Figure I-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table I-3. (Note – Calibration data to be used as reference only).

Table I-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 9			Test Duration : 1000-hrs.		
Test Fuel : Jet A-1 w/25-mg/L NALCO 5403 @ 135°F				SN : 15396953			SN : 15396954		
PUMP RPM	Description	Specification		Pump Duration : 1000.-hrs.			Pump Duration : 1000.-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	61 psi	ND		62 psi	62 psi	0 psi
	Return Fuel	225 cc	375 cc	330 cc	ND		**385 cc**	**410 cc**	-25 cc
350	Low Idle	12 cc	16 cc	13 cc	ND		14 cc	**0 cc**	14 cc
	Housing psi.	8 psi	12 psi	10.0 psi	ND		8.0 psi	10.0 psi	-2.0 psi
	Advance	3.50°		3.54°	ND		4.65°	4.14°	.51°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	ND		.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	ND		.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	ND		68.0 cc	**65.0 cc**	3.0 cc
1600	WOT Fuel delivery	60 cc		64 cc	ND		65 cc	61 cc	4 cc
	WOT Advance	2.50°	3.50°	3.39°	ND		3.07°	2.68°	.39°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	ND		22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.64°	ND		6.25°	5.44°	.81°
	Low Idle	11.0°	12.0°	11.2°	ND		11.1°	**10.9°**	.2°
1825	Fuel Delivery	33 cc		38 cc	ND		38 cc	**4 cc**	34 cc
1950	High Idle		15 cc	2 cc	ND		3 cc	0 cc	3 cc
	Transfer pump psi.		125 psi	106 psi	ND		105 psi	105 psi	0 psi
200	WOT Fuel Delivery	58 cc		62 cc	ND		61 cc	60 cc	1 cc
	WOT Shut-Off		4 cc	0 cc	ND		0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		54 cc	ND		48 cc	48 cc	cc
	Transfer pump psi.	16 psi		23 psi	ND		26 psi	25 psi	1 psi
	Housing psi.	.0 psi	12 psi	7.0 psi	ND		9 psi	10 psi	-1 psi
	Air Timing	-1.00°	.00°	-.50°	ND		-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :
Pump SN:15396953 drive shaft needle bearings were extremely worn and pump could not be calibrated.
Pump SN:15396954 Very low fuel delivery at 350 and 1825 rpm
ND = Not Determined

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table I-4 and Table I-5.

Table I-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396953	Test Number: 9	
Fuel Description : Jet A-1 w/25-mg/L NALCO 5403 @ 135°F				
	Date:	10/12/2010	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2324	3.2183	-0.0141
Measurement 2		3.2322	3.2181	-0.0141
Measurement 3		3.2322	3.2182	-0.0140
Measurement 4		3.2324	3.2181	-0.0143
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2586	3.2453	-0.0133
Measurement 2		3.2585	3.2453	-0.0132
Measurement 3		3.2585	3.2452	-0.0133
Measurement 4		3.2584	3.2452	-0.0132
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2819	3.2700	-0.0119
Measurement 2		3.2819	3.2702	-0.0117
Measurement 3		3.2820	3.2702	-0.0118
Measurement 4		3.2818	3.2701	-0.0117
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2716	3.2618	-0.0098
Measurement 2		3.2717	3.2619	-0.0098
Measurement 3		3.2717	3.2619	-0.0098
Measurement 4		3.2718	3.2618	-0.0100
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2323	3.2182	-0.0141
Transfer Pump Blade 2		3.2585	3.2453	-0.0133
Transfer Pump Blade 3		3.2819	3.2701	-0.0118
Transfer Pump Blade 4		3.2717	3.2619	-0.0099
	Roller to Roller (in)	1.9760	1.9758	-0.0002
	Eccentricity (in.)	0.0060	0.0040	-0.0020
	Drive Backlash (In)	0.0040	0.0045	0.0005

Table I-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)	SN: 15396954	Test Number: 9
Fuel Description : Jet A-1 w/25-mg/L NALCO 5403 @ 135°F		

	Date:	10/2/2010	10/19/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2452	3.2494	0.0042
Measurement 2		3.2452	3.2495	0.0043
Measurement 3		3.2451	3.2493	0.0042
Measurement 4		3.2452	3.2494	0.0042
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.1890	3.1959	0.0069
Measurement 2		3.1891	3.1957	0.0066
Measurement 3		3.1890	3.1956	0.0066
Measurement 4		3.1891	3.1957	0.0066
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2045	3.2089	0.0044
Measurement 2		3.2046	3.2087	0.0041
Measurement 3		3.2044	3.2087	0.0043
Measurement 4		3.2045	3.2088	0.0043
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2296	3.2326	0.0030
Measurement 2		3.2297	3.2324	0.0027
Measurement 3		3.2295	3.2325	0.0030
Measurement 4		3.2295	3.2324	0.0029
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2452	3.2494	0.0042
Transfer Pump Blade 2		3.1891	3.1957	0.0067
Transfer Pump Blade 3		3.2045	3.2088	0.0043
Transfer Pump Blade 4		3.2296	3.2325	0.0029
	Roller to Roller (in)	1.9760	1.9748	-0.0012
	Eccentricity (in.)	0.0030	0.0010	-0.0020
	Drive Backlash (In)	0.0050	0.0000	-0.0050

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table I-6.

Table I-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection												
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist		
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	
9	15396953	Jet A-1 w/25-mg/L NALCO 5403 @ 135°F	9-1	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass	
			9-2	2175	1800	Pass	Pass	Pass	Pass	Pass	Pass	
			9-3	2175	1800	Pass	Pass	Pass	Pass	Pass	Pass	
			9-4	1950	1850	Pass	Pass	Pass	Pass	Pass	Pass	
			9-5	2150	1800	Pass	Pass	Pass	Pass	Pass	Pass	
			9-6	2150	1725	Pass	Pass	Pass	Pass	Pass	Pass	
			9-7	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass	
			9-8	2125	1675	Pass	Pass	Pass	Pass	Pass	Pass	
9	15396954	Jet A-1 w/25-mg/L NALCO 5403 @ 135°F	9-11	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass	
			9-12	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass	
			9-13	2125	1775	Pass	Pass	Pass	Pass	Pass	Pass	
			9-14	2150	1850	Pass	Pass	Pass	Pass	Pass	Pass	
			9-15	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass	
			9-16	2125	1725	Pass	Pass	Pass	Pass	Pass	Pass	
			9-17	2150	1750	Pass	Pass	Pass	Pass	Pass	Pass	
			9-18	2150	1725	Pass	Pass	Pass	Pass	Pass	Pass	
			Passed 16 out of 16									

Comments : ______________________________

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table I-7 and Table I-8.

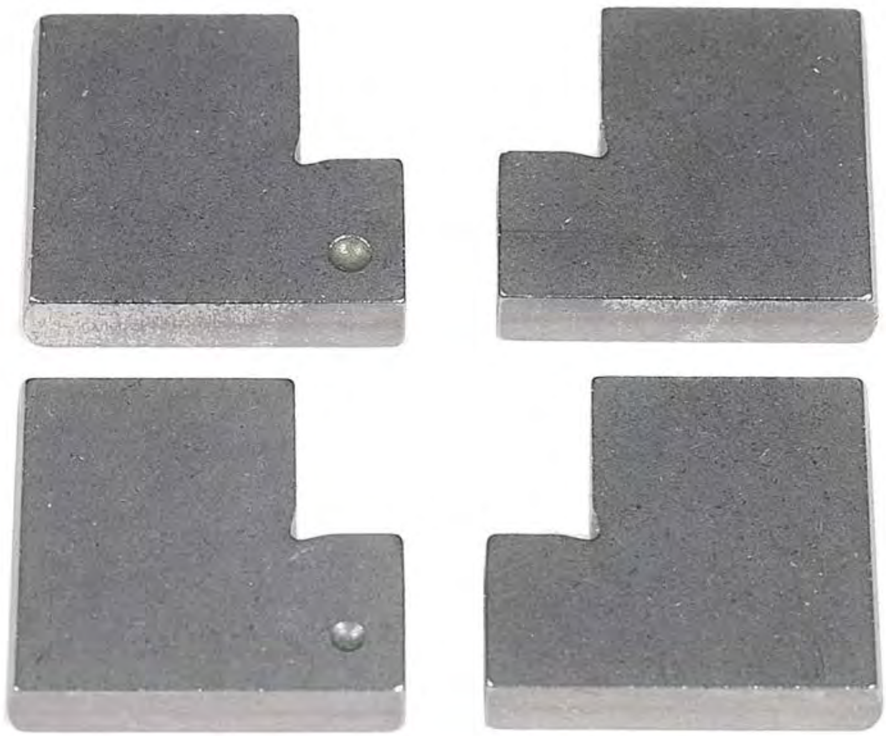
Table I-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15396953
Test Condition : Jet A-1 w/25-mg/L NALCO 5403 @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at slots and liner contact	2
BLADE SPRINGS	Very light wear at spots	1
LINER	70% Wear on surface	2
TRANSFER PUMP REGULATOR	Deposits on inlet side. Scuffing marks	2
REGULATOR PISTON	Deposits and polished in spots	1.5
ROTOR	Wear line at distributor ports	1.5
ROTOR RETAINERS	Wear from rotor contacts	1.5
DELIVERY VALVE	Light polishing wear	1
PLUNGERS	Polishing wear	1.5
SHOES	Medium wear at contact points	1.5
ROLLERS	Discolored	1.5
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Normal polishing wear from governor fingers	1
GOVORNER WEIGHTS	Wear at foot of weight from thrust washer	2
LINK HOOK	Normal	1
METERING VAVLE	Deposits and light polishing	1
DRIVE SHAFT TANG	Polishing from rotor contact	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	In spec	1
ADVANCE PISTON	Polishing wear in spots	2.5
HOUSING	Brown deposits	1
	AVERAGE DEMERIT RATINGS	1.391

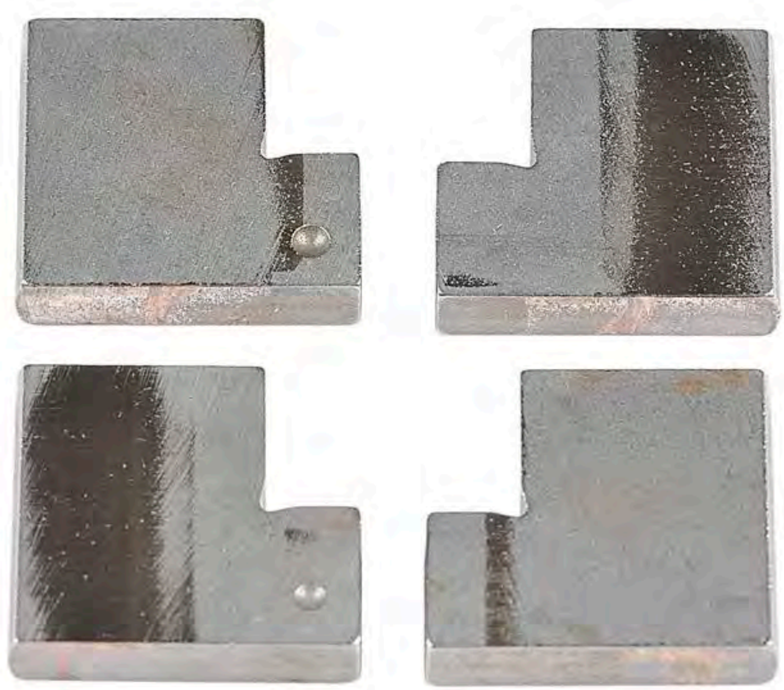
Table I-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15396954
Test Condition : Jet A-1 w/25-mg/L NALCO 5403 @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at slots and liner contact	2
BLADE SPRINGS	Very light wear at spots	1
LINER	80% Wear on surface	2.5
TRANSFER PUMP REGULATOR	Deposits on inlet side. Scuffing marks	2
REGULATOR PISTON	Deposits and polished in spots	1
ROTOR	Wear line at distributor ports	2.5
ROTOR RETAINERS	Wear from rotor contacts	1.5
DELIVERY VALVE	Light polishing wear	1
PLUNGERS	Polishing wear. Discoloration on left plunger	2
SHOES	Medium wear at contact points	1.5
ROLLERS	Discolored	1.5
LEAF SPRING	Wear from shoe contact	1
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Normal polishing wear from governor fingers	2
GOVORNER WEIGHTS	Wear at foot of weight from thrust washer	1
LINK HOOK	Normal	1
METERING VAVLE	Deposits and light polishing	1
DRIVE SHAFT TANG	Polishing from rotor contact	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	In spec	1
ADVANCE PISTON	Scuffing and polishing	3
HOUSING	Brown deposits	1
	AVERAGE DEMERIT RATINGS	1.457

PHOTOGRAPHS FOR LEFT PUMP



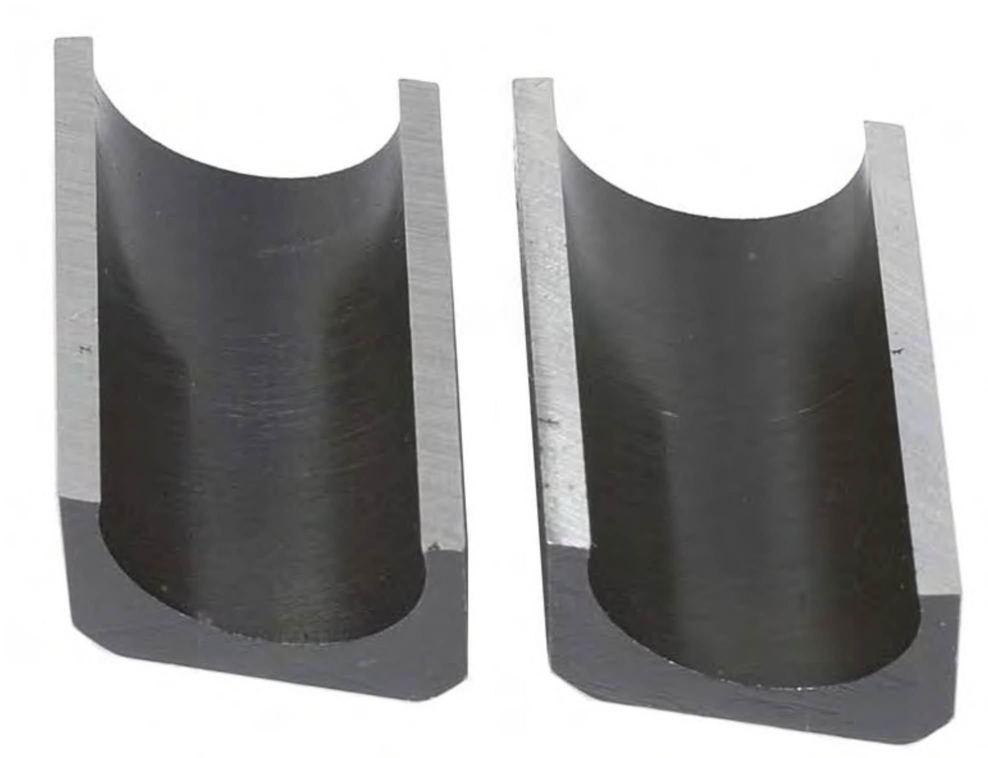
SN15396953 Transfer Pump Blades (Side), Before



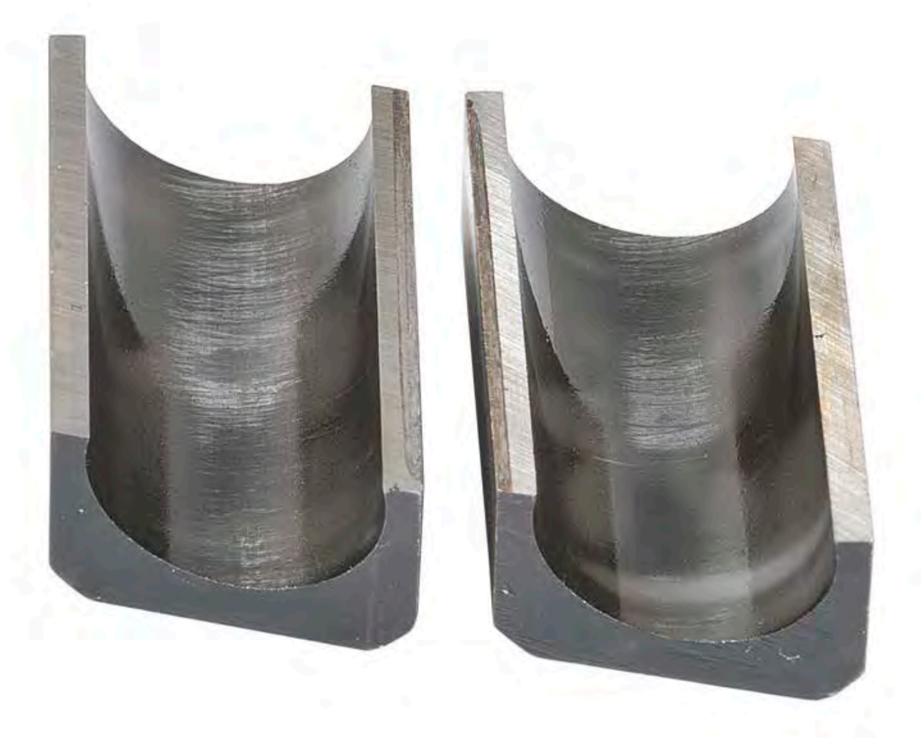
SN15396953 Transfer Pump Blades (Side), After

SN15396953 Transfer Pump Blades (Profile), Before

SN15696953 Transfer Pump Blades (Profile), After



SN15396953 Shoes (Front), Before



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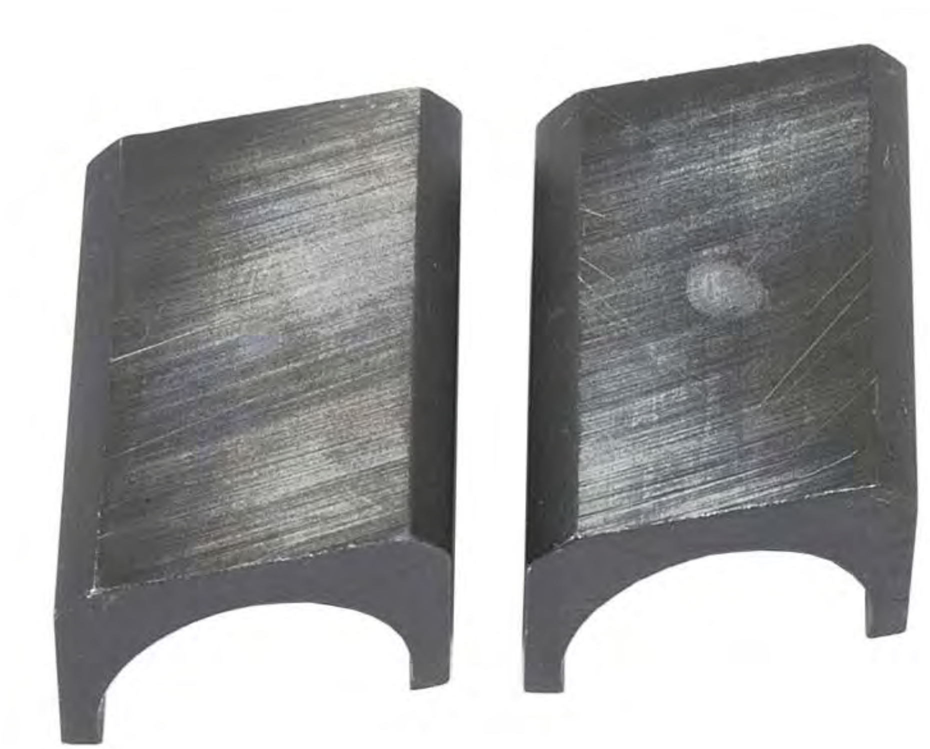


SN15396953 Shoes (Back), Before

SN15396953 Shoes (Back), After

SN15396953 Rollers, Before

SN15396953 Rollers, After

SN15396953 Piston Plungers, Before

SN15396953 Piston Plungers, After

SN15396953 Thrust Washer, Before

SN15396953 Thrust Washer, After

SN15396953 Governor Weight, Before

SN15396953 Governor Weight, After

SN15396953 Cam Ring, Before

SN15396953 Cam Ring, After

SN15396953 Eccentric Ring, Before

SN15396953 Eccentric Ring, After

SN15396953 Rotor (Front), Before

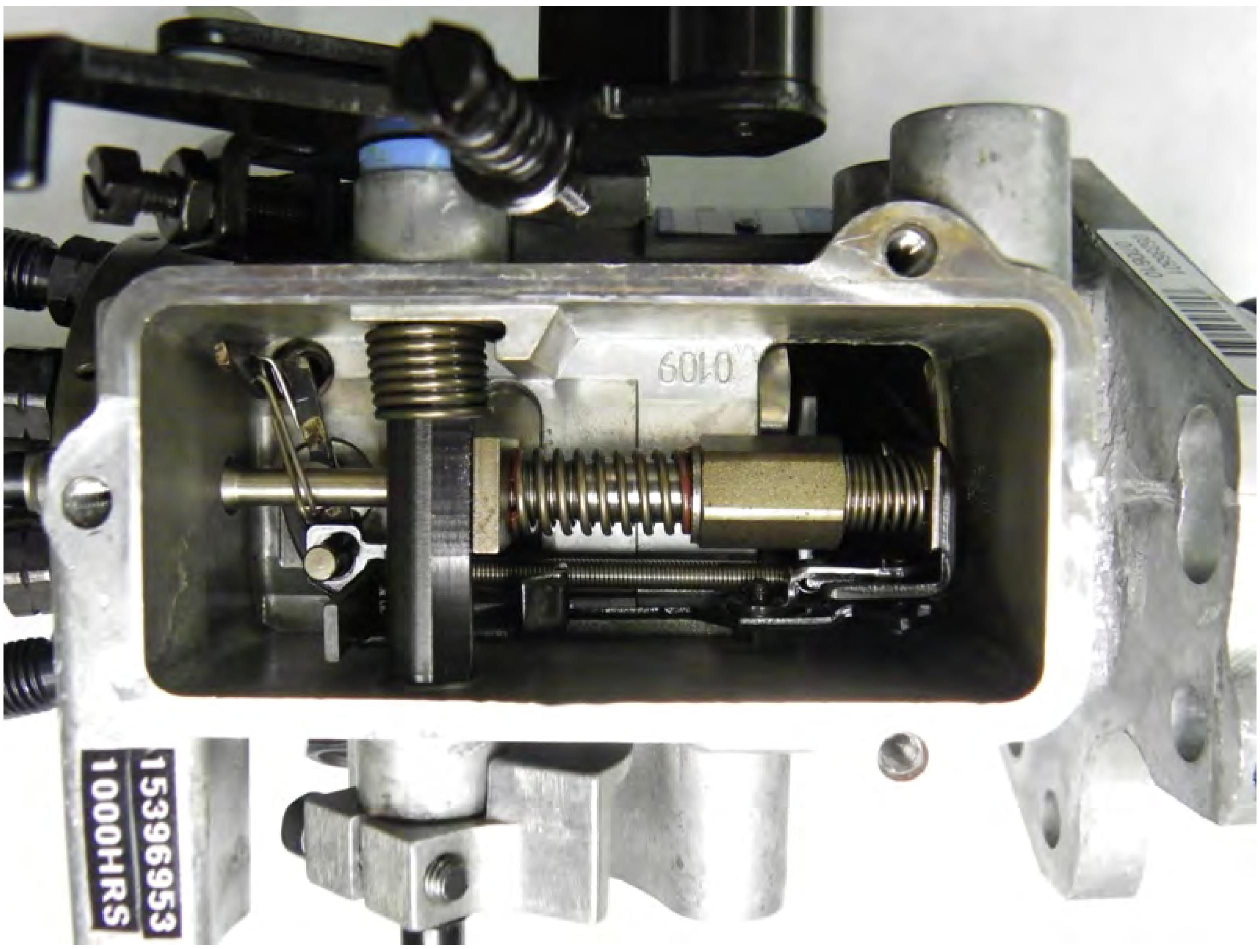
SN15396953 Rotor (Front), After

SN15396953 Rotor (Back), Before

SN15396953 Rotor (Back), After

SN15396953 Drive Tang, Before

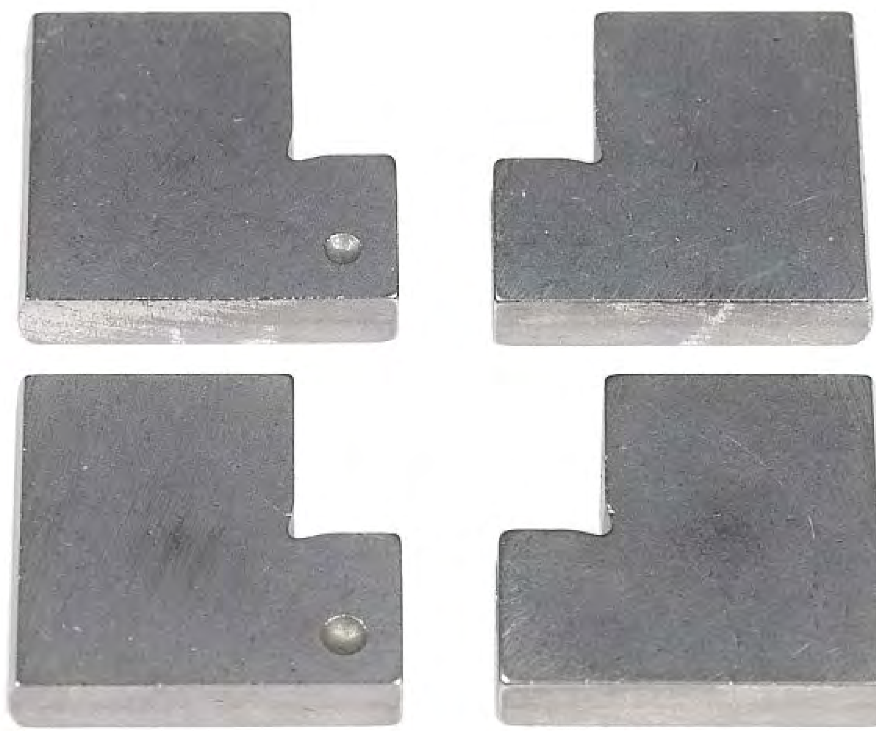
SN15396953 Drive Tang, After



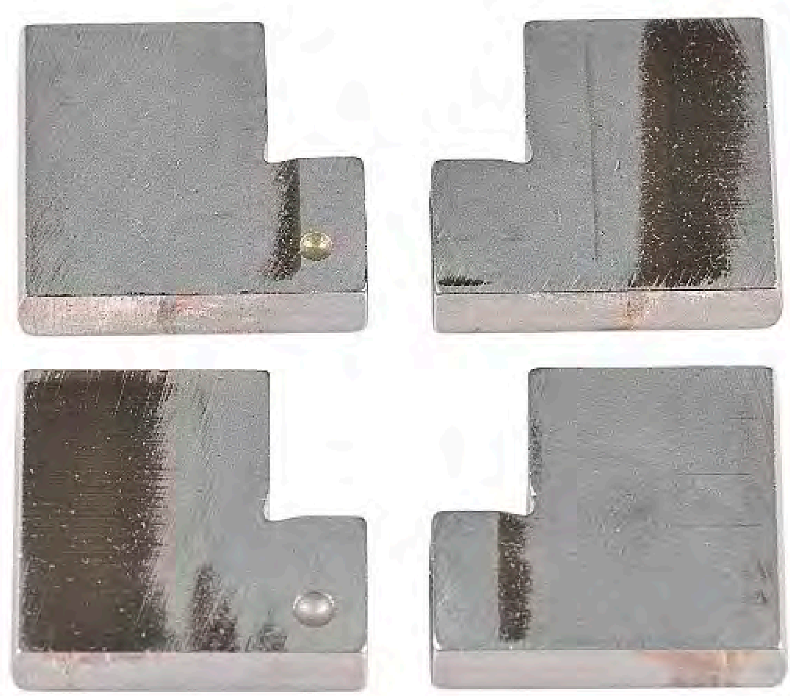
SN15396953 Governor Assembly, After

SN15396953 Transfer Pump Regulator Assembly, After

PHOTOGRAPHS FOR RIGHT PUMP



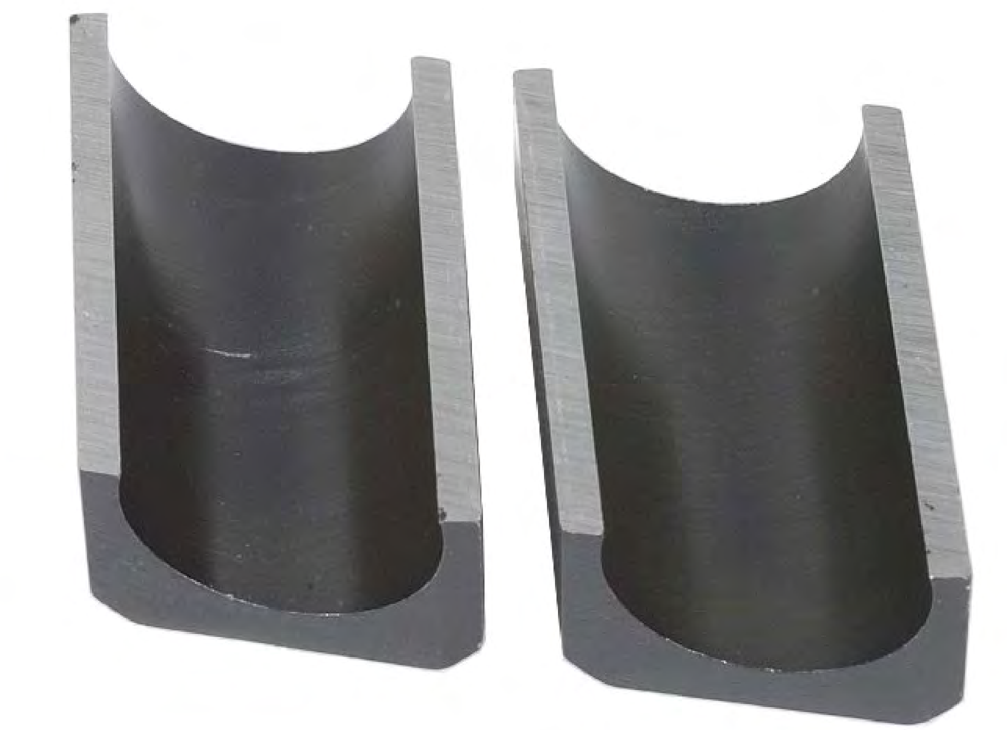
SN15396954 Transfer Pump Blades, Before



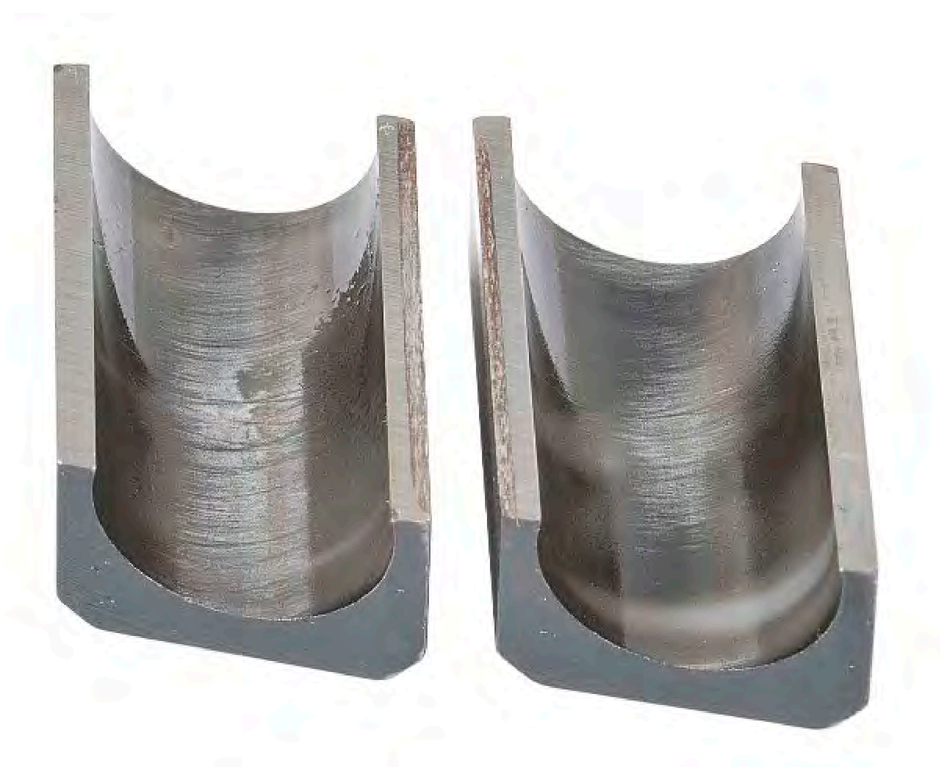
SN15396954 Transfer Pump Blades, After

SN15396954 Transfer Pump Blades (Profile), Before

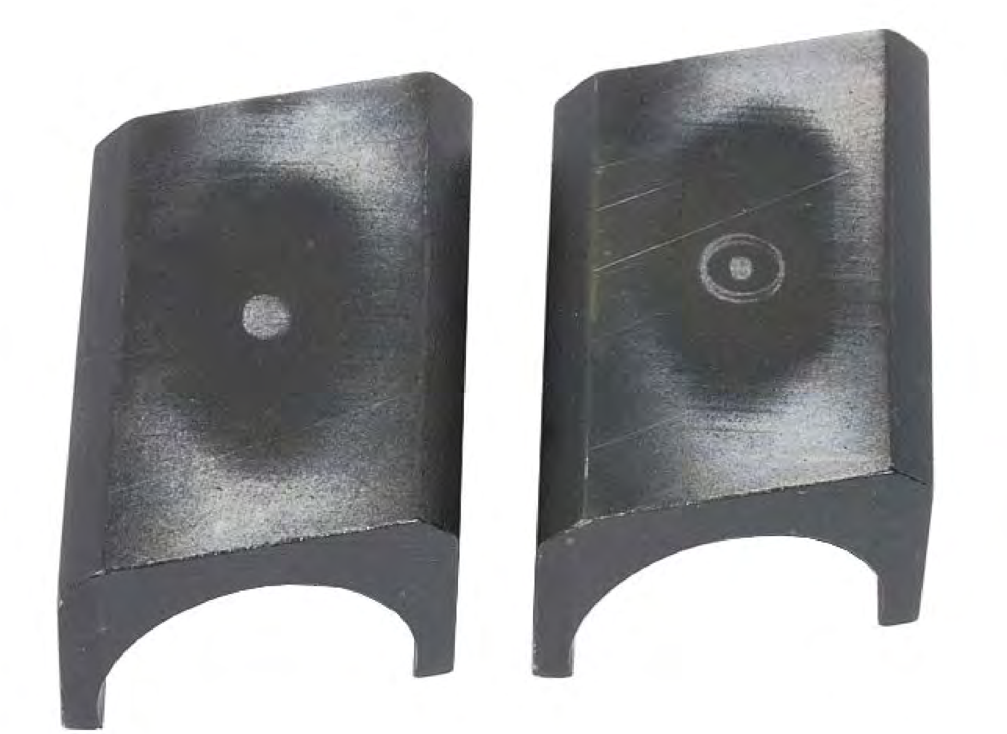
SN15396954 Transfer Pump Blades (Profile), After



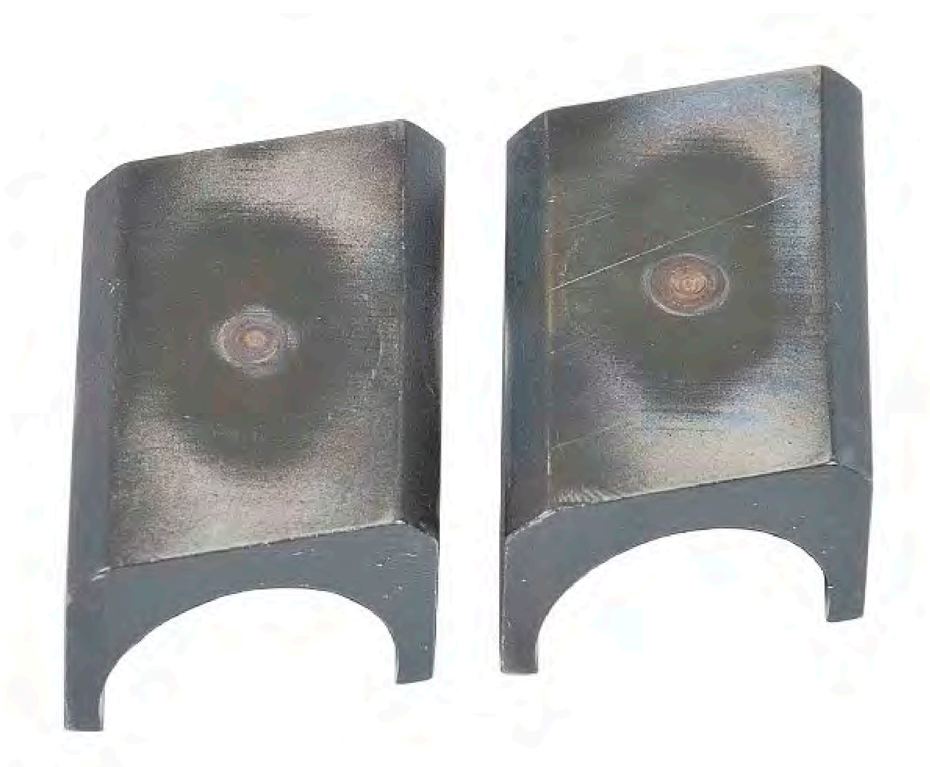
SN15396954 Shoes (Front), Before



SN15396954 Shoes (Front), After



SN15396954 Shoes (Back), Before



SN15396954 Shoes (Back), After

SN15396954 Rollers, Before

SN15396954 Rollers, After

SN15396954 Piston Plungers, Before

SN15396954 Piston Plungers, After

SN15396954 Thrust Washer, Before

SN15396954 Thrust Washer, After

SN15396954 Governor Weight, Before

SN15396954 Governor Weight, After

SN15396954 Cam Ring, Before

SN15396954 Cam Ring, After

SN15396954 Eccentric Ring, Before

SN15396954 Eccentric Ring, After

SN1596954 Rotor (Front), Before

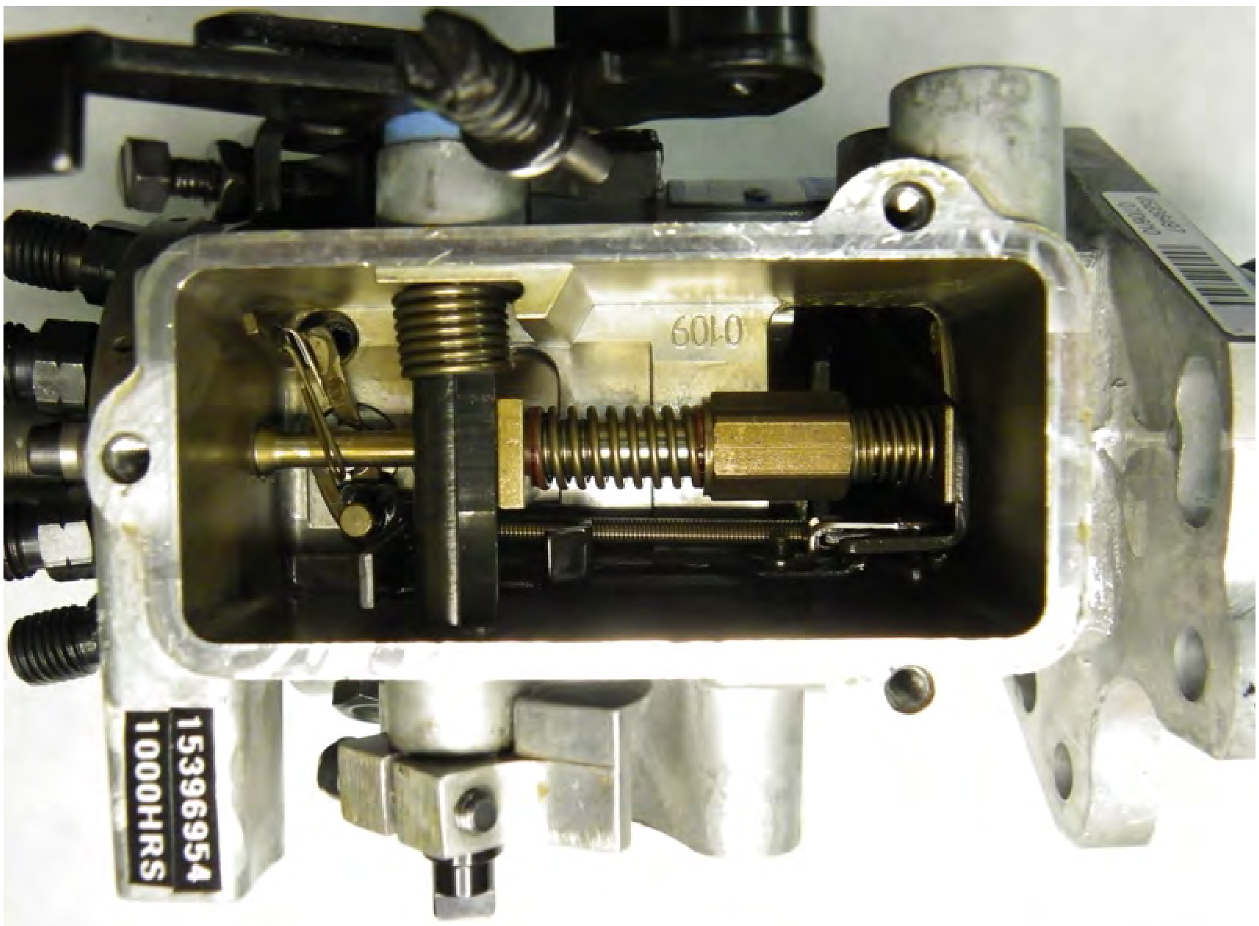
SN1596954 Rotor (Front), After

SN15396954 Rotor (Back), Before

SN15396954 Rotor (Back), After

SN15396954 Drive Tang, Before

SN15396954 Drive Tang, After



SN15396954 Governor Assembly, After

SN15396954 Transfer Pump Regulator Assembly, After

APPENDIX J

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 22.5-mg/L DCI-4A
Test Number: C3T10-77-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 22.5-mg/L DCI-4A

Test Fuel ID: AF7090

Test Temperature: 77°C (170°F)

Test Number: C3T10-77-1000

Start of Test Date: June 8, 2011

End of Test Date: August 12, 2011

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure J-1.

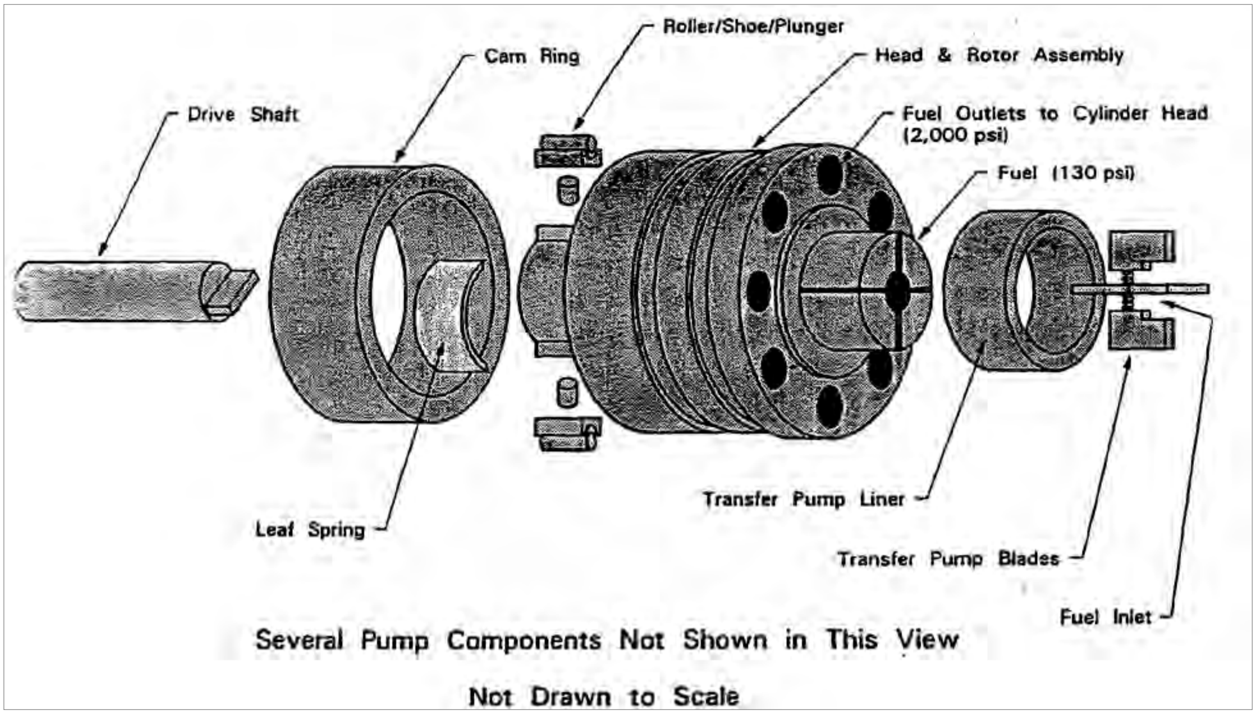


Figure J-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table J-1.

Table J-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	77 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table J-2.

Table J-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.0275
FLO_R	Injected Flow-rate [mL/min]	721.1	21.7
FUELIN_P	Fuel Inlet Pressure [psig]	3	0.035
TRNS_P_R	Transfer Pump Pressure [psig]	68	1.34
HSG_P_R	Pump Housing Pressure [psig]	13.1	0.46
RTRN_T_R	Fuel Return Temperature [°C]	81.2	0.81
FUEL_T	Fuel Tank Temperature [°C]	30.5	1.3
FUELIN_T	Fuel Inlet Temperature [°C]	76.7	0.33

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure J-2 through Figure J-4.

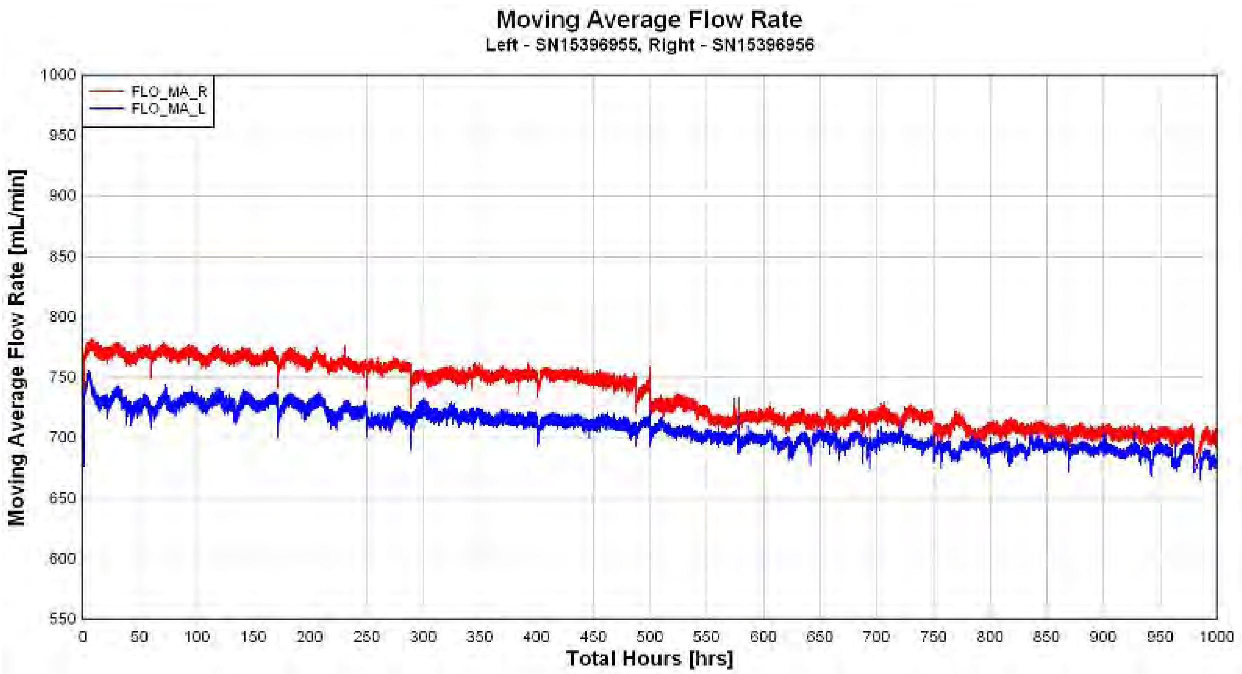


Figure J-2. Pump Flow, Moving Average

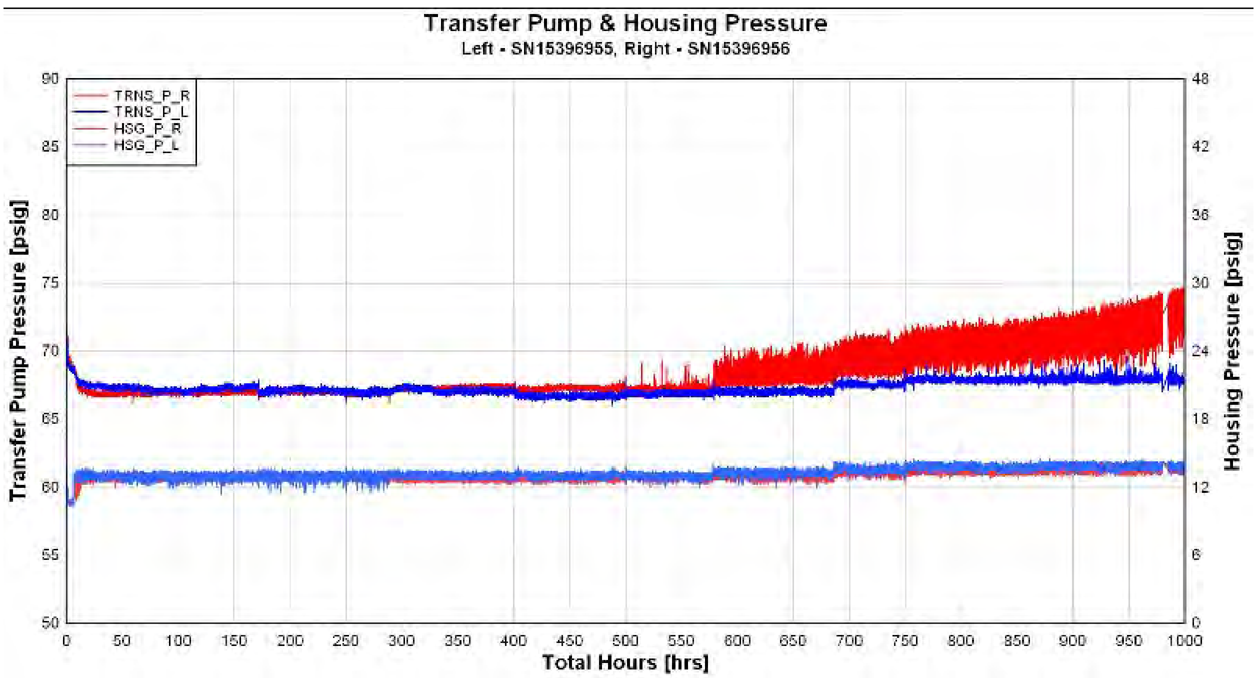


Figure J-3. Transfer Pump & Housing Pressure

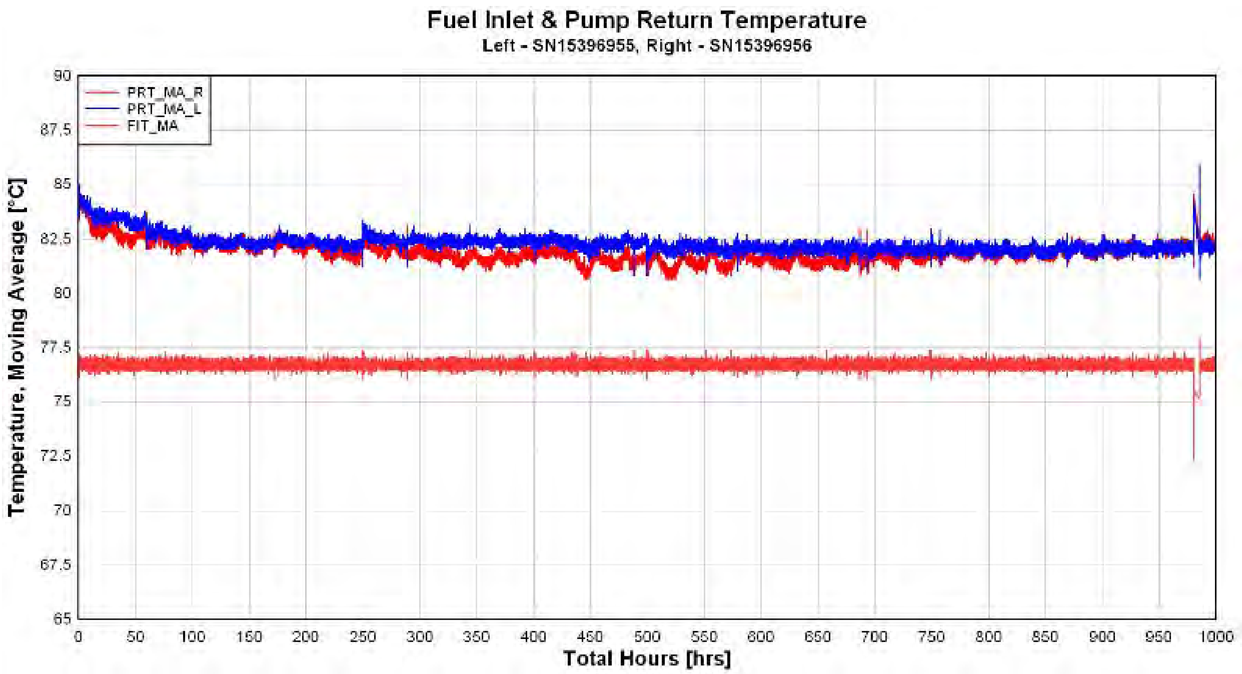


Figure J-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in J-3. (Note – Calibration data to be used as reference only).

Table J-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 10			Test Duration : 1000-hrs.		
Test Fuel : Jet A-1 with 22.5-mg/L DCI-4A @ 170°F				SN : 15396955			SN : 15396956		
PUMP RPM	Description	Specification		Pump Duration : 1000.-hrs.			Pump Duration : 1000.-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	62 psi	psi	61 psi	**63 psi**	-2 psi
	Return Fuel	225 cc	375 cc	320 cc	**420 cc**	-100 cc	285 cc	326 cc	-41 cc
350	Low Idle	12 cc	16 cc	15 cc	**17 cc**	-2 cc	14 cc	16 cc	-2 cc
	Housing psi.	8 psi	12 psi	10.0 psi	9.5 psi	.5 psi	10.0 psi	10.0 psi	.0 psi
	Advance	3.50°		3.62°	3.69°	-.07°	3.64°	3.99°	-.35°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	**65.0 cc**	2.0 cc	67.0 cc	**66.0 cc**	1.0 cc
1600	WOT Fuel delivery	60 cc		63 cc	60 cc	3 cc	65 cc	60 cc	5 cc
	WOT Advance	2.50°	3.50°	3.00°	3.40°	-.40°	3.27°	3.47°	-.20°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.30°	6.19°	.11°	6.37°	6.46°	-.09°
	Low Idle	11.0°	12.0°	11.1°	11.1°	-.1°	11.1°	**10.5°**	.5°
1825	Fuel Delivery	33 cc		38 cc	40 cc	-2 cc	37 cc	46 cc	-9 cc
1950	High Idle		15 cc	2 cc	3 cc	-1 cc	1 cc	2 cc	-1 cc
	Transfer pump psi.		125 psi	105 psi	105 psi	0 psi	104 psi	106 psi	-2 psi
200	WOT Fuel Delivery	58 cc		59 cc	68 cc	-9 cc	61 cc	59 cc	2 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		47 cc	44 cc	3 cc	51 cc	48 cc	3 cc
	Transfer pump psi.	16 psi		26 psi	21 psi	5 psi	31 psi	29 psi	2 psi
	Housing psi.	.0 psi	12 psi	7.0 psi	8 psi	-1 psi	6 psi	9 psi	-3 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table J-4 and Table A-5.

Table J-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396955	Test Number: 10	
Fuel Description : Jet A-1 with 22.5-mg/L DCI-4A @ 170°F				
	Date:	10/2/2010	10/25/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2414	3.2423	0.0009
Measurement 2		3.2415	3.2423	0.0008
Measurement 3		3.2414	3.2422	0.0008
Measurement 4		3.2415	3.2423	0.0008
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2663	3.2689	0.0026
Measurement 2		3.2664	3.2687	0.0023
Measurement 3		3.2665	3.2687	0.0022
Measurement 4		3.2664	3.2688	0.0024
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2523	3.2554	0.0031
Measurement 2		3.2522	3.2553	0.0031
Measurement 3		3.2523	3.2553	0.0030
Measurement 4		3.2524	3.2552	0.0028
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2190	3.2197	0.0007
Measurement 2		3.2191	3.2195	0.0004
Measurement 3		3.2191	3.2195	0.0004
Measurement 4		3.2190	3.2194	0.0004
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2415	3.2423	0.0008
Transfer Pump Blade 2		3.2664	3.2688	0.0024
Transfer Pump Blade 3		3.2523	3.2553	0.0030
Transfer Pump Blade 4		3.2191	3.2195	0.0005
	Roller to Roller (in)	1.9760	1.9749	-0.0011
	Eccentricity (in.)	0.0095	0.0120	0.0025
	Drive Backlash (In)	0.0050	0.0060	0.0010

Table J-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15396956	Test Number: 10	
Fuel Description : Jet A-1 with 22.5-mg/L DCI-4A @ 170°F				
	Date:	10/2/2010	10/26/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2482	3.2532	0.0050
Measurement 2		3.2480	3.2532	0.0052
Measurement 3		3.2480	3.2532	0.0052
Measurement 4		3.2481	3.2532	0.0051
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2430	3.2469	0.0039
Measurement 2		3.2431	3.2468	0.0037
Measurement 3		3.2429	3.2467	0.0038
Measurement 4		3.2429	3.2468	0.0039
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2489	3.2509	0.0020
Measurement 2		3.2487	3.2507	0.0020
Measurement 3		3.2490	3.2506	0.0016
Measurement 4		3.2489	3.2507	0.0018
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2573	3.2608	0.0035
Measurement 2		3.2575	3.2609	0.0034
Measurement 3		3.2574	3.2610	0.0036
Measurement 4		3.2575	3.2610	0.0035
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2481	3.2532	0.0051
Transfer Pump Blade 2		3.2430	3.2468	0.0038
Transfer Pump Blade 3		3.2489	3.2507	0.0019
Transfer Pump Blade 4		3.2574	3.2609	0.0035
	Roller to Roller (in)	1.9760	1.9747	-0.0013
	Eccentricity (in.)	0.0080	0.0080	0.0000
	Drive Backlash (In)	0.0055	0.0075	0.0020

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table J-6.

Table J-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
10	15396955	Jet A-1 with 22.5-mg/L DCI-4A @ 170°F	10-1	2050	1925	Pass	Pass	Pass	Pass	Pass	Pass
			10-2	2125	1950	Pass	Pass	Pass	Pass	Pass	Pass
			10-3	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			10-4	2100	1925	Pass	Pass	Pass	Pass	Pass	Pass
			10-5	2175	1925	Pass	Pass	Pass	Pass	Pass	Pass
			10-6	2150	1975	Pass	Pass	Pass	Pass	Pass	Pass
			10-7	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			10-8	2075	1925	Pass	Pass	Pass	Pass	Pass	Pass
10	15396956	Jet A-1 with 22.5-mg/L DCI-4A @ 170°F	10-11	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			10-12	2175	1900	Pass	Pass	Pass	Pass	Pass	Pass
			10-13	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			10-14	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			10-15	2125	1900	Pass	Pass	Pass	Pass	Pass	Pass
			10-16	2175	1975	Pass	Pass	Pass	Pass	Pass	Pass
			10-17	2200	1925	Pass	Pass	Pass	Pass	Pass	Pass
			10-18	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments : ______________________________

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table J-7 and Table J-8.

Table J-7. Stanadyne Left Pump Parts Evaluation

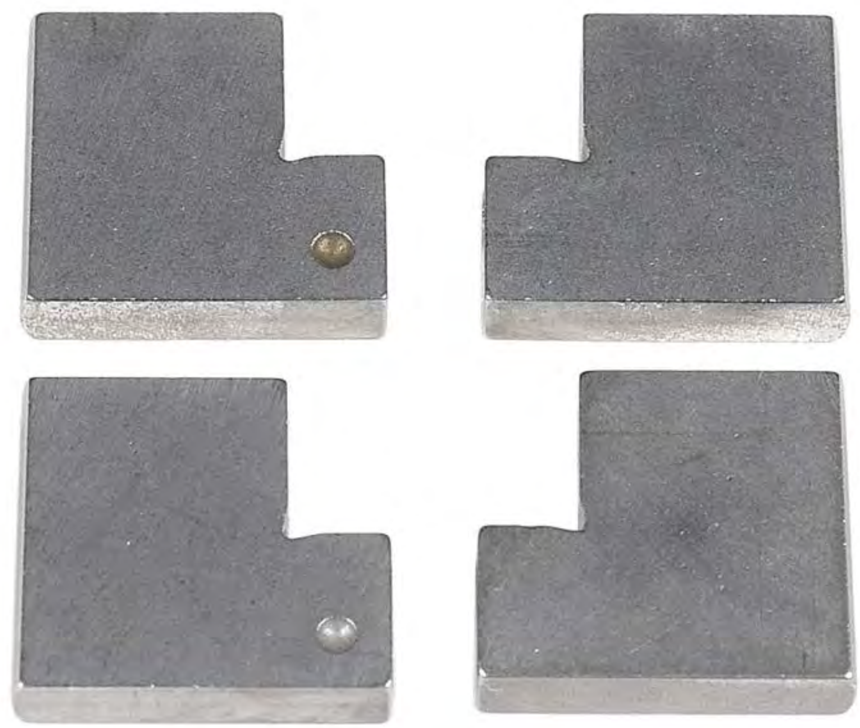
Pump Type :		SN: 15396955
Test Condition : Jet A-1 with 22.5-mg/L DCI-4A @ 170°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	1.5
BLADE SPRINGS	Normal	1
LINER	Polishing wear on 60% of surface	1.5
TRANSFER PUMP REGULATOR	Light wear from blades & rotor contact	1.5
REGULATOR PISTON	Wear mark in one spot	1.5
ROTOR	Polishing wear marks at inlet and outlet ports	1
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear in spots	1.5
PLUNGERS	Polishing wear	1.5
SHOES	Medium wear at contact points	1.5
ROLLERS	Polishing Wear	1
LEAF SPRING	Light wear from shoe contact	1
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Light wear from governor arm fingers	1
GOVORNER WEIGHTS	Wear from T washer contact	1.5
LINK HOOK	Normal	1
METERING VAVLE	Polishing wear. Brown deposits	1
DRIVE SHAFT TANG	Polishing wear from rotor contact	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	In specification	1
ADVANCE PISTON	Scoring and polishing wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.283

Table J-8. Stanadyne Right Pump Parts Evaluation

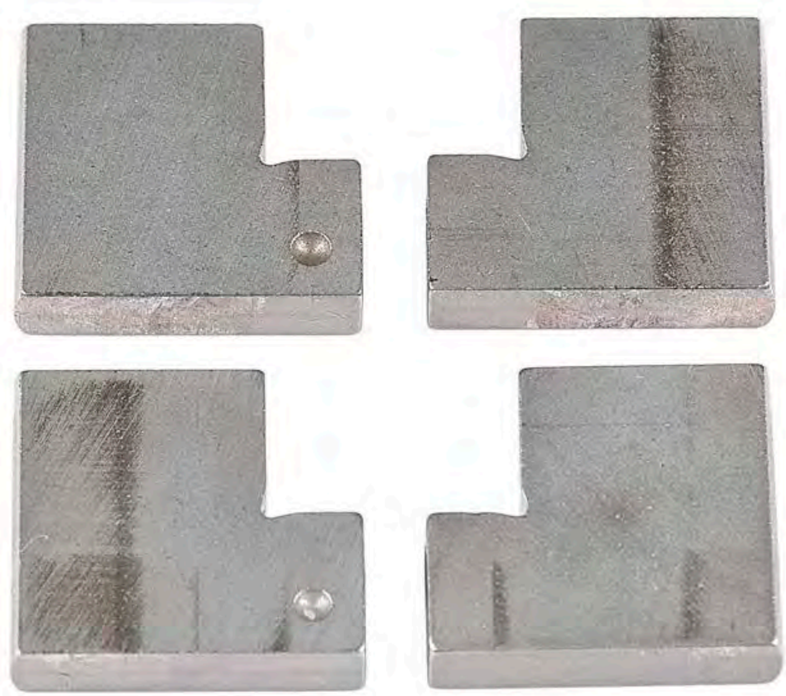
Pump Type :	SN: 15396956
Test Condition : Jet A-1 with 22.5-mg/L DCI-4A @ 170°F	Pump Duration : 1000.-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Wear at rotor slots and liner contact	1.5
BLADE SPRINGS	Normal	1
LINER	Polishing wear on 60% of surface	1.5
TRANSFER PUMP REGULATOR	Light wear from rotor contact	1
REGULATOR PISTON	Light polishing in one spot.	1
ROTOR	Polishing wear marks at inlet and outlet ports	1.5
ROTOR RETAINERS	Wear from rotor contact	1.5
DELIVERY VALVE	Polishing wear in spots	1
PLUNGERS	Polishing wear	1.5
SHOES	Medium wear at contact points	1.5
ROLLERS	Polishing Wear	1
LEAF SPRING	Light wear from shoe contact	1.5
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Light wear from governor arm fingers (Brown deposits)	1
GOVORNER WEIGHTS	Wear from T washer contact	1.5
LINK HOOK	Normal	1
METERING VAVLE	Polishing wear. (Brown deposits)	1
DRIVE SHAFT TANG	Polishing wear from rotor contact	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	In specification	1
ADVANCE PISTON	Scoring and polishing wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.261

PHOTOGRAPHS FOR LEFT PUMP



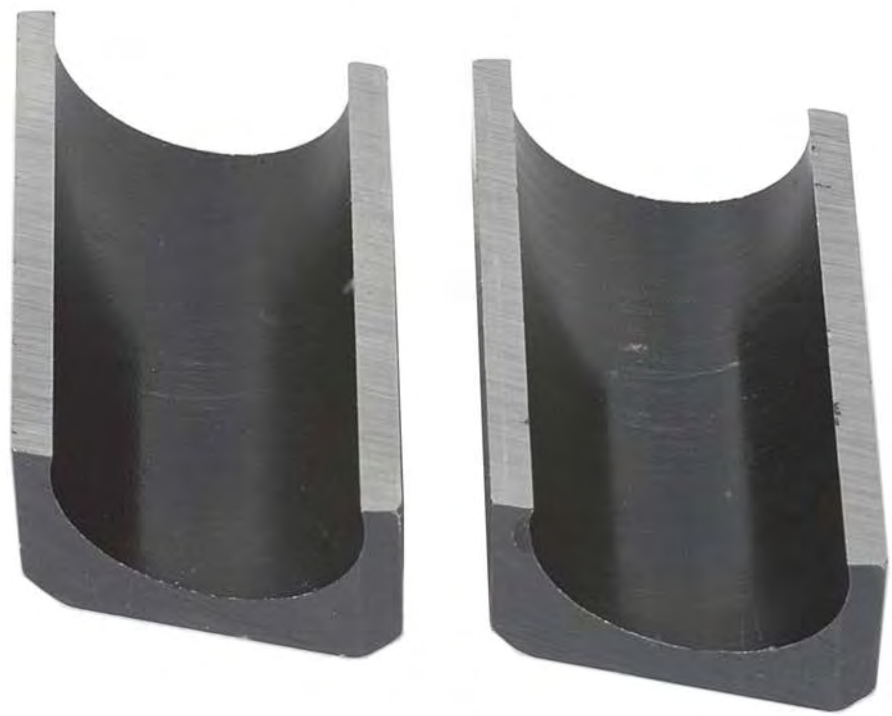
SN15396955 Transfer Pump Blades (Side), Before



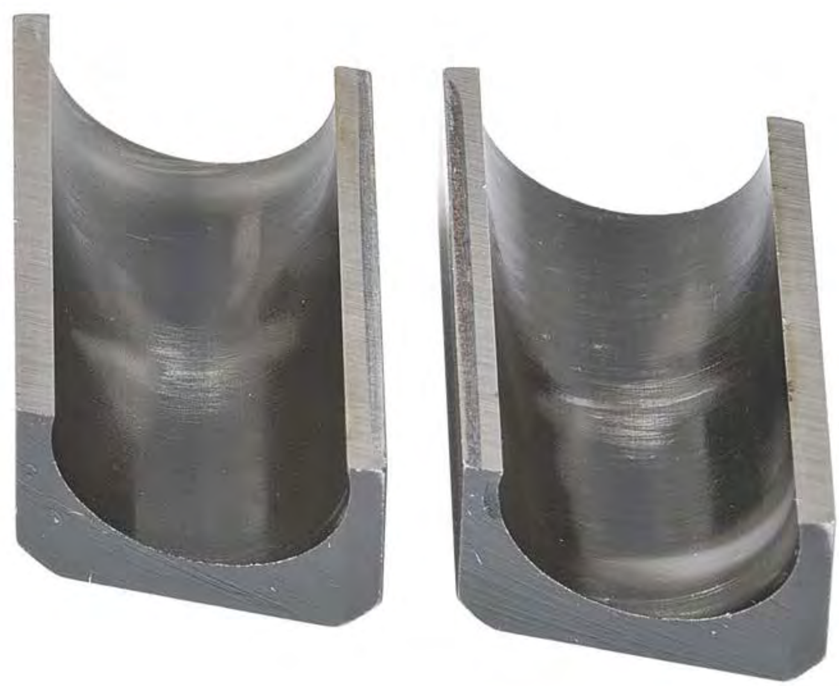
SN15396955 Transfer Pump Blades (Side), After

SN15396955 Transfer Pump Blades (Profile), Before

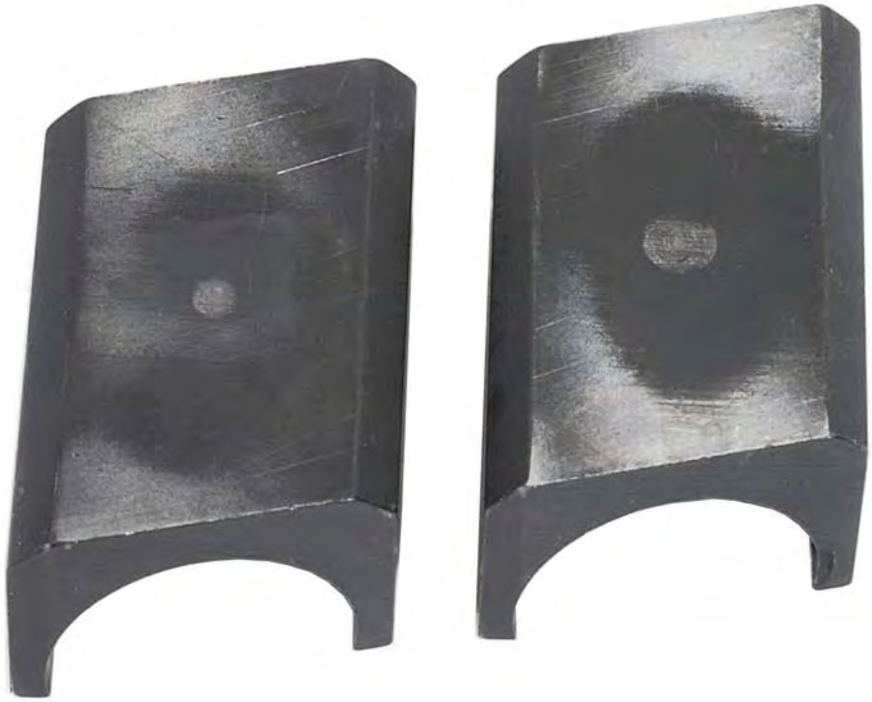
SN15396955 Transfer Pump Blades (Profile), After



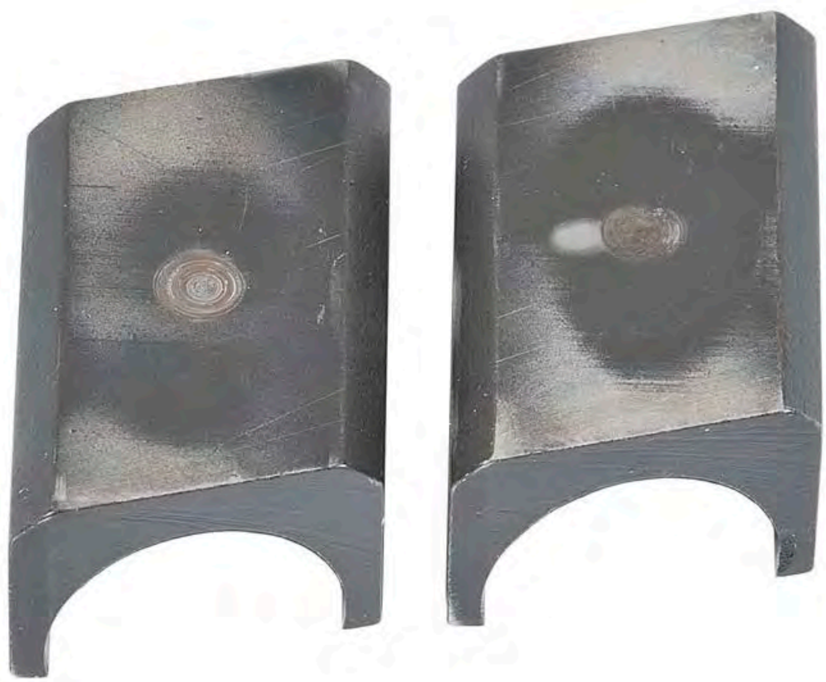
SN15396955 Shoes (Front), Before



SN15396955 Shoes (Front), After



SN15396955 Shoes (Back), Before



SN15396955 Shoes (Back), After

SN15396955 Rollers, Before

SN15396955 Rollers, After

SN15396955 Piston Plungers, Before

SN15396955 Piston Plungers, After

SN15396955 Thrust Washer, Before

SN15396955 Thrust Washer, After

SN15396955 Governor Weight, Before

SN15396955 Governor Weight, After

SN15396955 Cam Ring, Before

SN15396955 Cam Ring, After

SN15396955 Eccentric Ring, Before

SN15396955 Eccentric Ring, After

SN15396955 Rotor (Front), Before

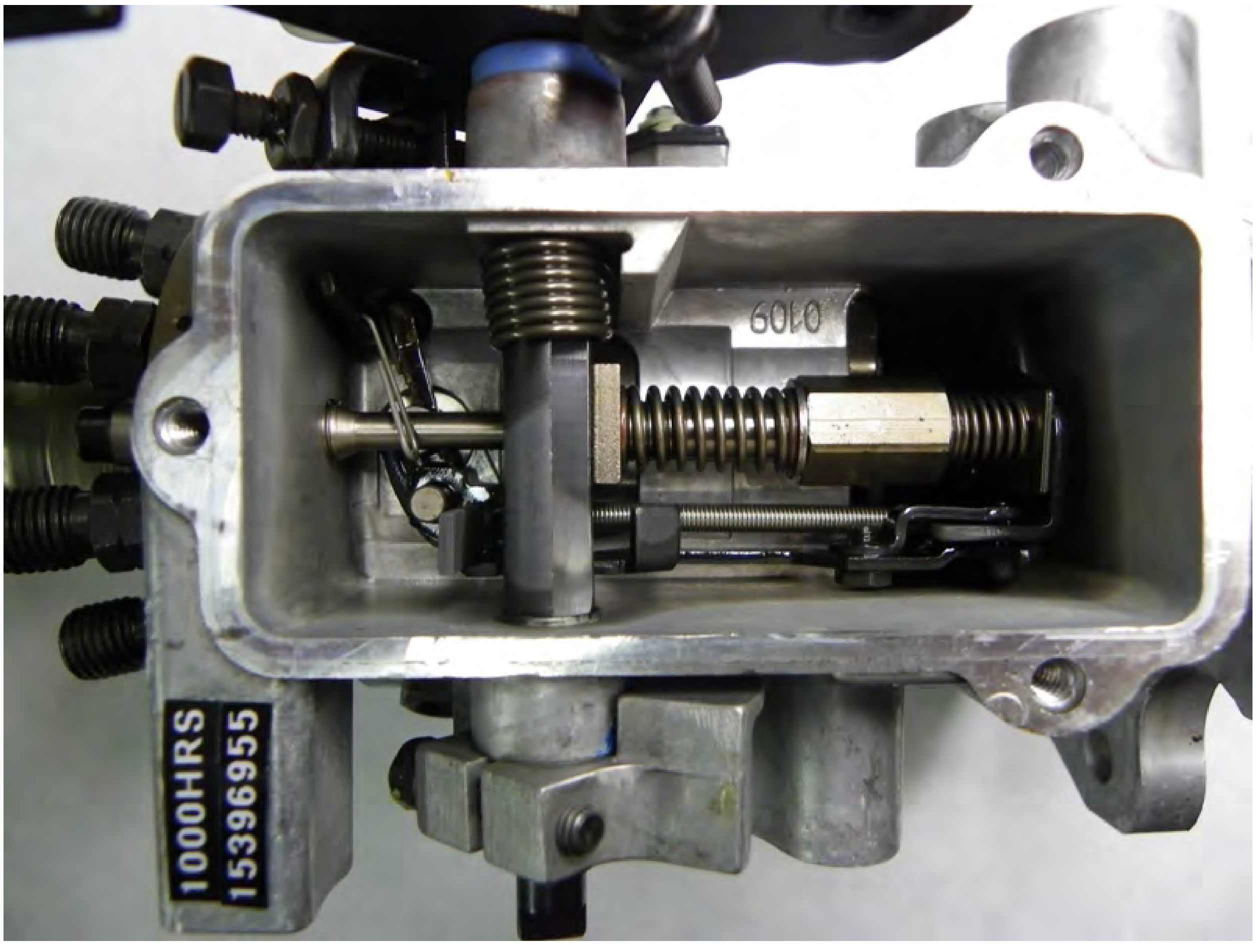
SN15396955 Rotor (Front), After

SN15396955 Rotor (Back), Before

SN15396955 Rotor (Back), After

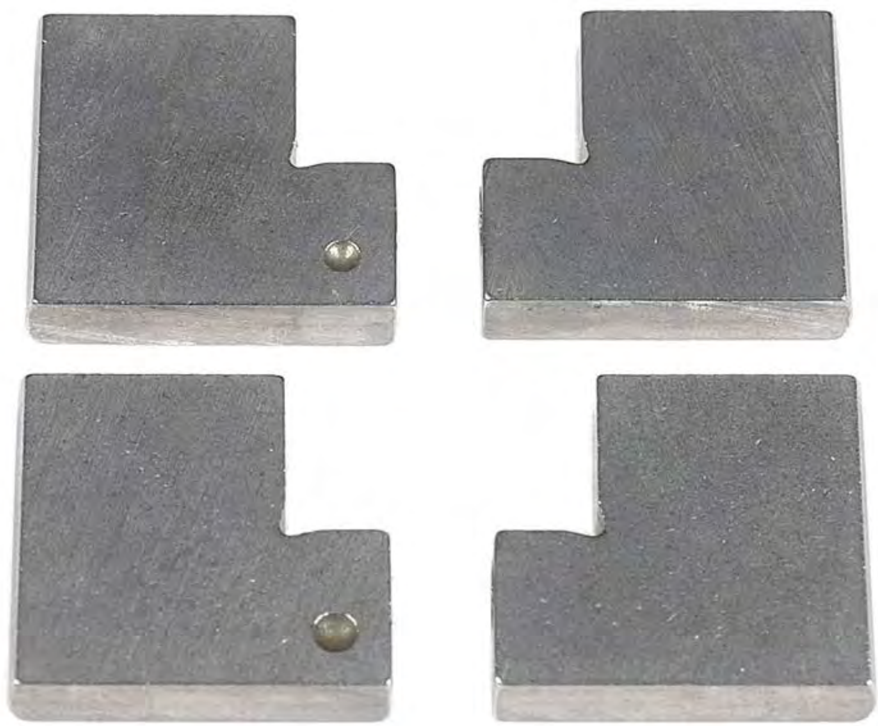
SN15396955 Drive Tang, Before

SN15396955 Drive Tang, After

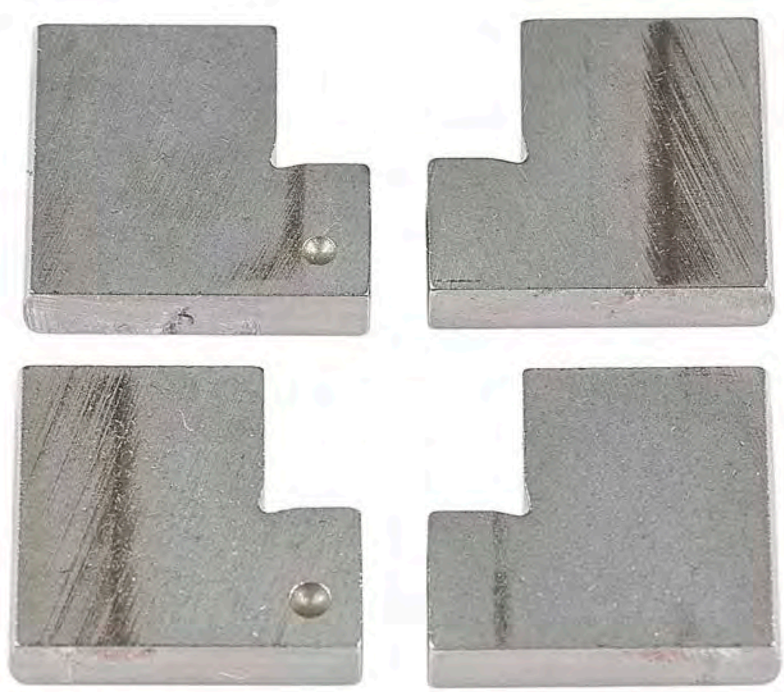


SN15396455 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



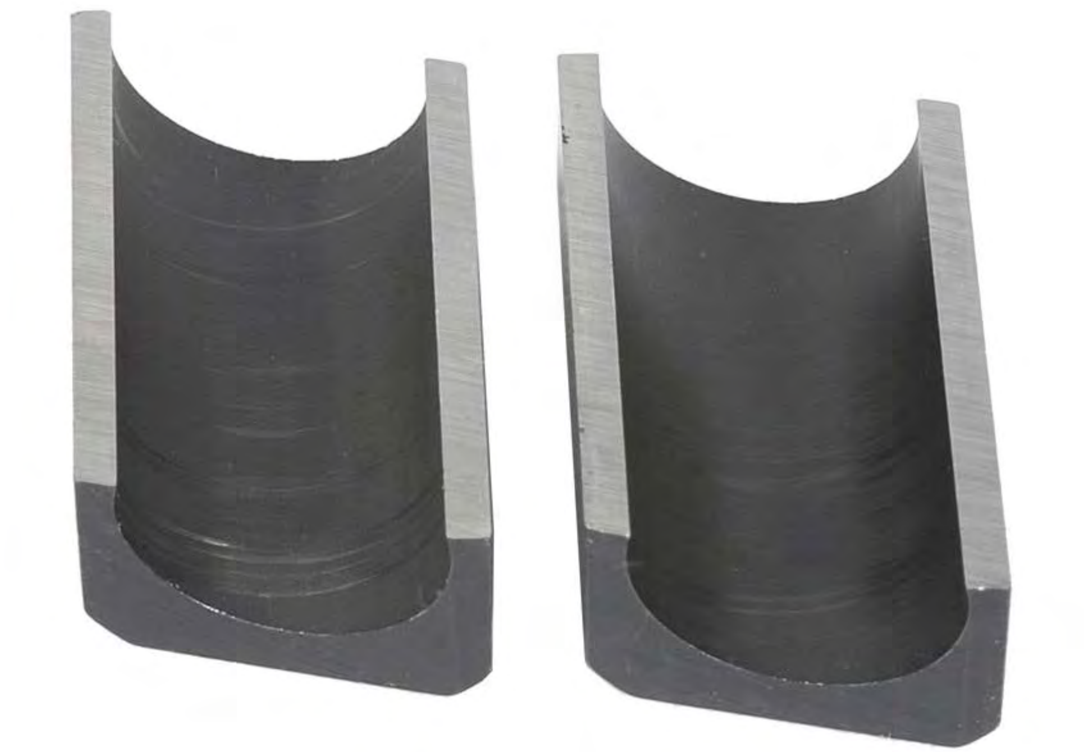
SN15396956 Transfer Pump Blades, Before



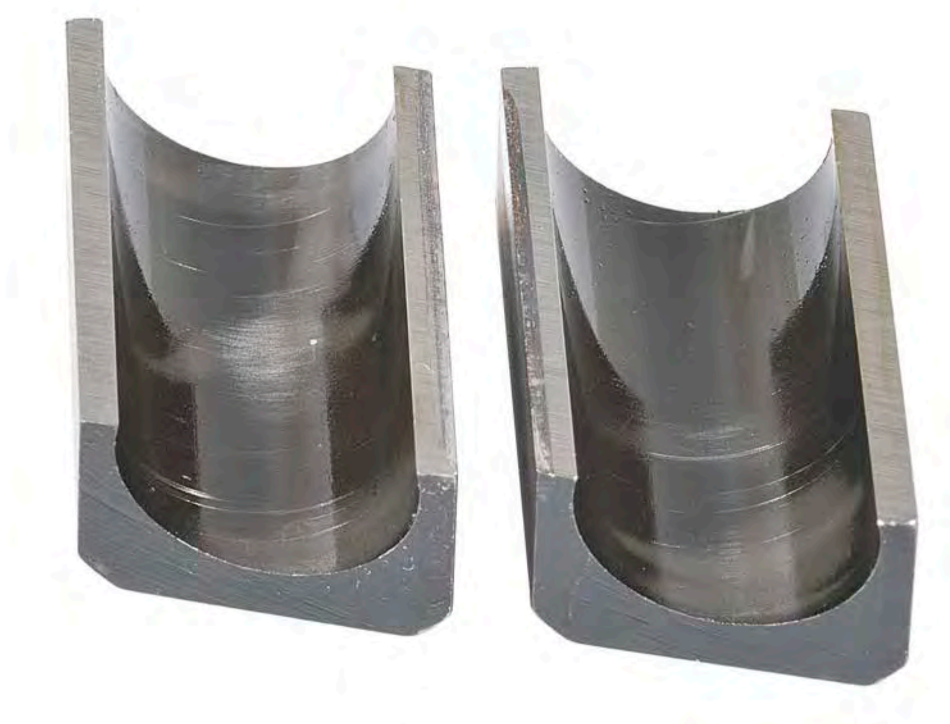
SN15396956 Transfer Pump Blades, After

SN15396956 Transfer Pump Blades (Profile), Before

SN15396956 Transfer Pump Blades (Profile), After



SN15396956 Shoes (Front), Before



SN15396956 Shoes (Front), After

SN15396956 Shoes (Back), Before

SN15396956 Shoes (Back), After

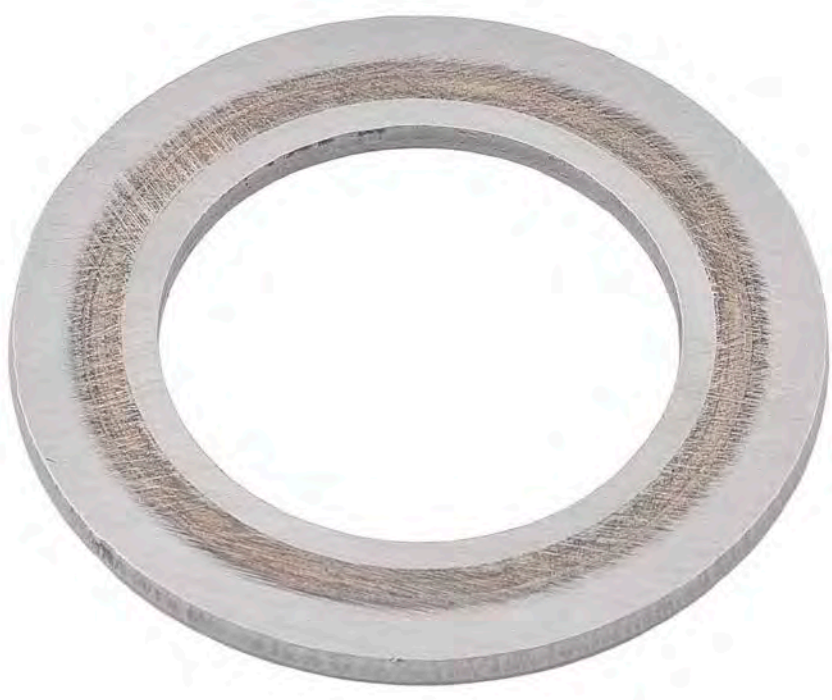
SN15396956 Rollers, Before

SN15396956 Rollers, After

SN15396956 Piston Plungers, Before

SN15396956 Piston Plungers, After

SN15396956 Thrust Washer, Before

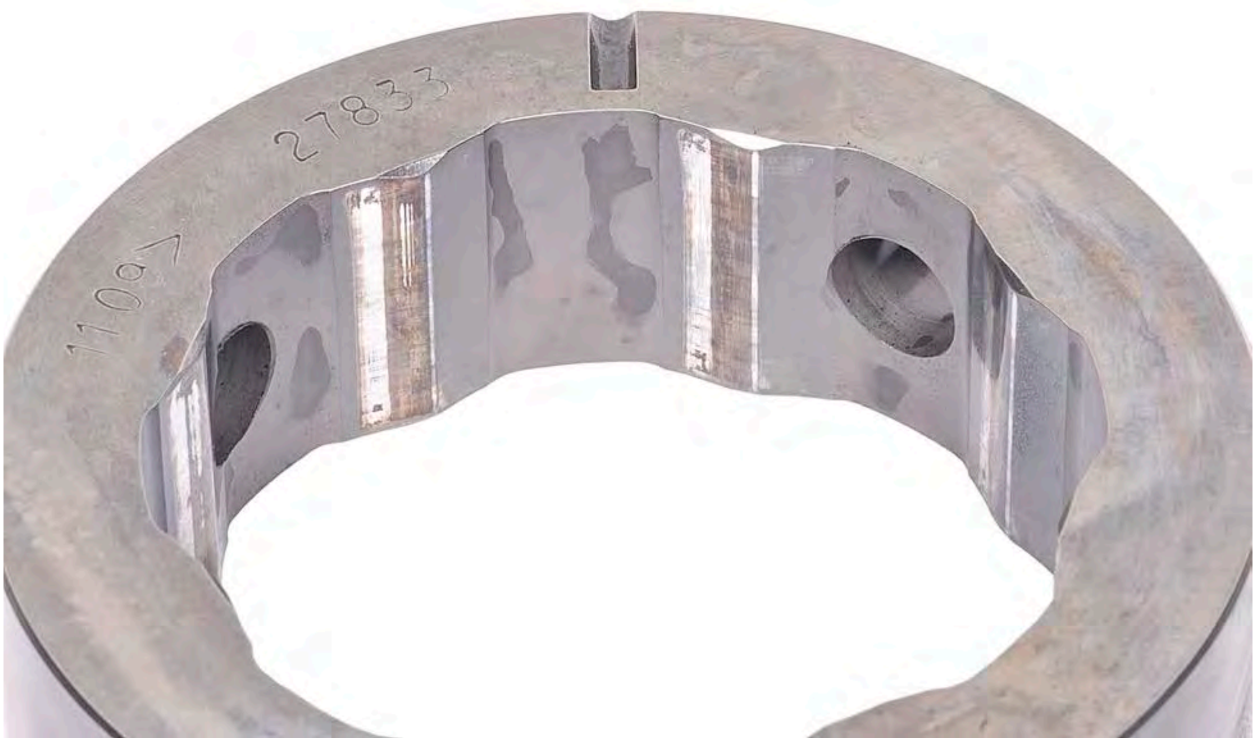


SN15396956 Thrust Washer, After

SN15396956 Governor Weight, Before

SN15396956 Governor Weight, After

SN15396956 Cam Ring, Before



SN15396956 Cam Ring, After

SN15396956 Eccentric Ring, Before

SN15396956 Eccentric Ring, After

SN1596956 Rotor (Front), Before

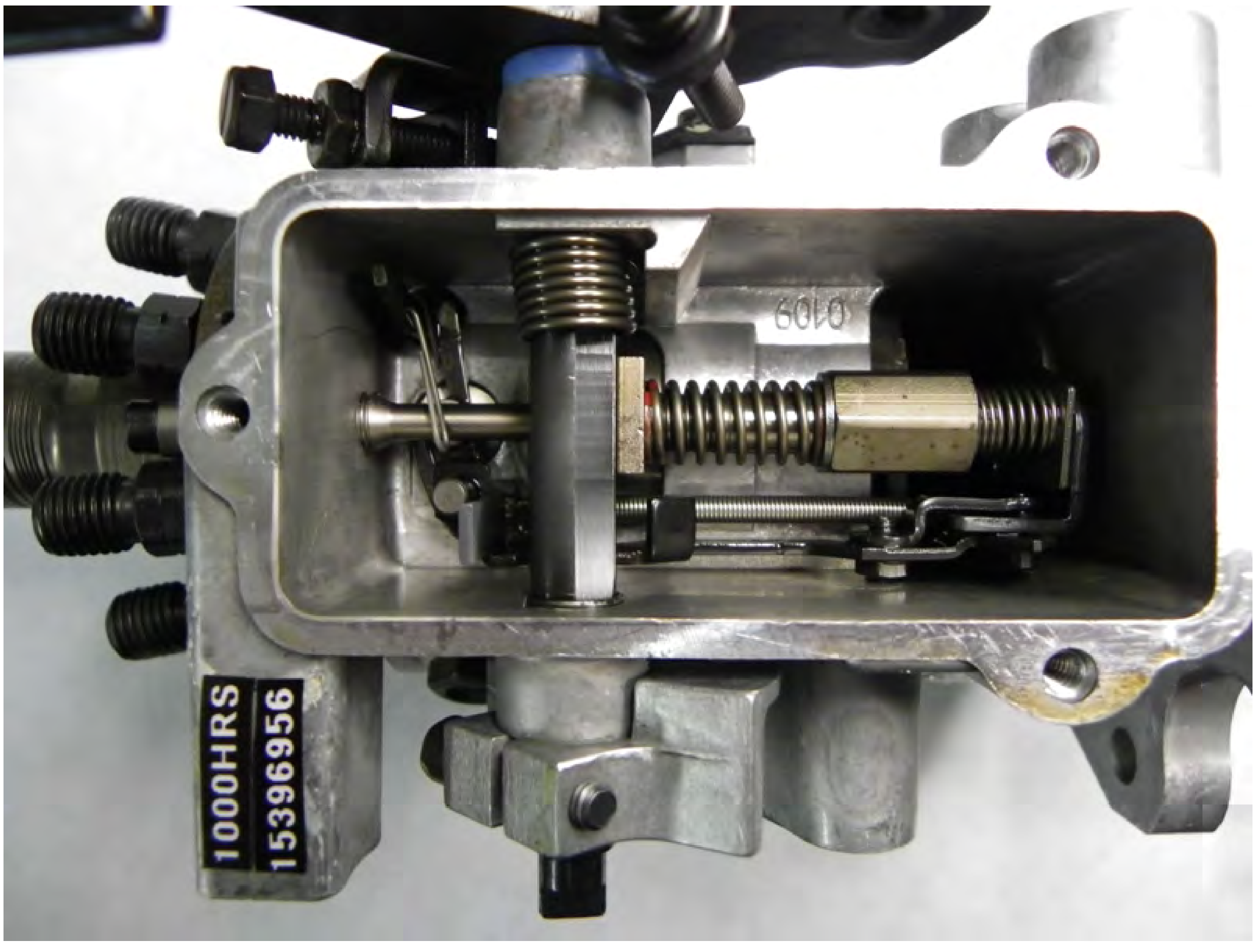
SN1596956 Rotor (Front), After

SN15396956 Rotor (Back), Before

SN15396956 Rotor (Back), After

SN15396956 Drive Tang, Before

SN15396956 Drive Tang, After



SN15396956 Governor Assembly

APPENDIX K

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 25-mg/L NALCO 5403
Test Number: C4T11-77-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 25-mg/L NALCO 5403
Test Fuel ID: AF7090
Test Temperature: 77°C (170°F)
Test Number: C4T11-77-1000
Start of Test Date: June 23, 2011
End of Test Date: August 30, 2011
Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure K-1.

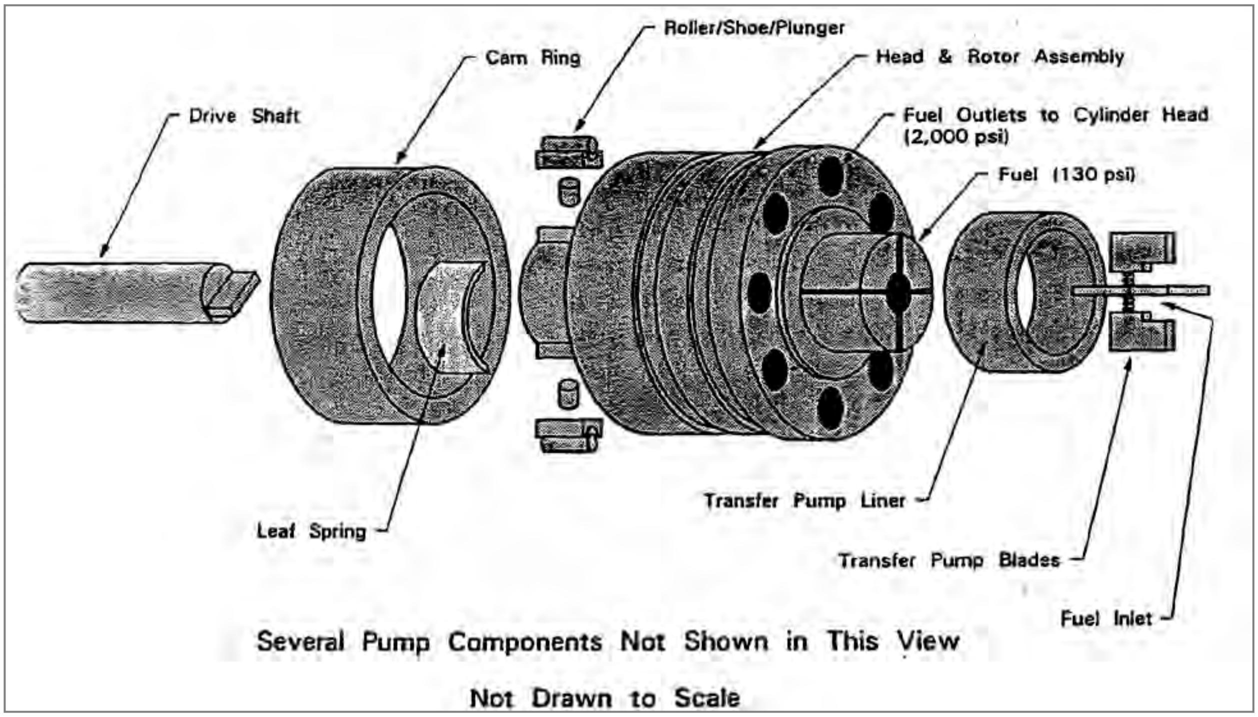


Figure K-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table K-1.

Table K-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	77 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table K-2.

Table K-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1701	2.57
FLO_R	Injected Flow-rate [mL/min]	708.8	17.62
FUELIN_P	Fuel Inlet Pressure [psig]	3	0.18
TRNS_P_R	Transfer Pump Pressure [psig]	78.9	0.72
HSG_P_R	Pump Housing Pressure [psig]	13.2	0.79
RTRN_T_R	Fuel Return Temperature [°C]	81.2	1.4
FUEL_T	Fuel Tank Temperature [°C]	30.9	2.72
FUELIN_T	Fuel Inlet Temperature [°C]	76.7	0.34

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure K-2 through Figure K-4.

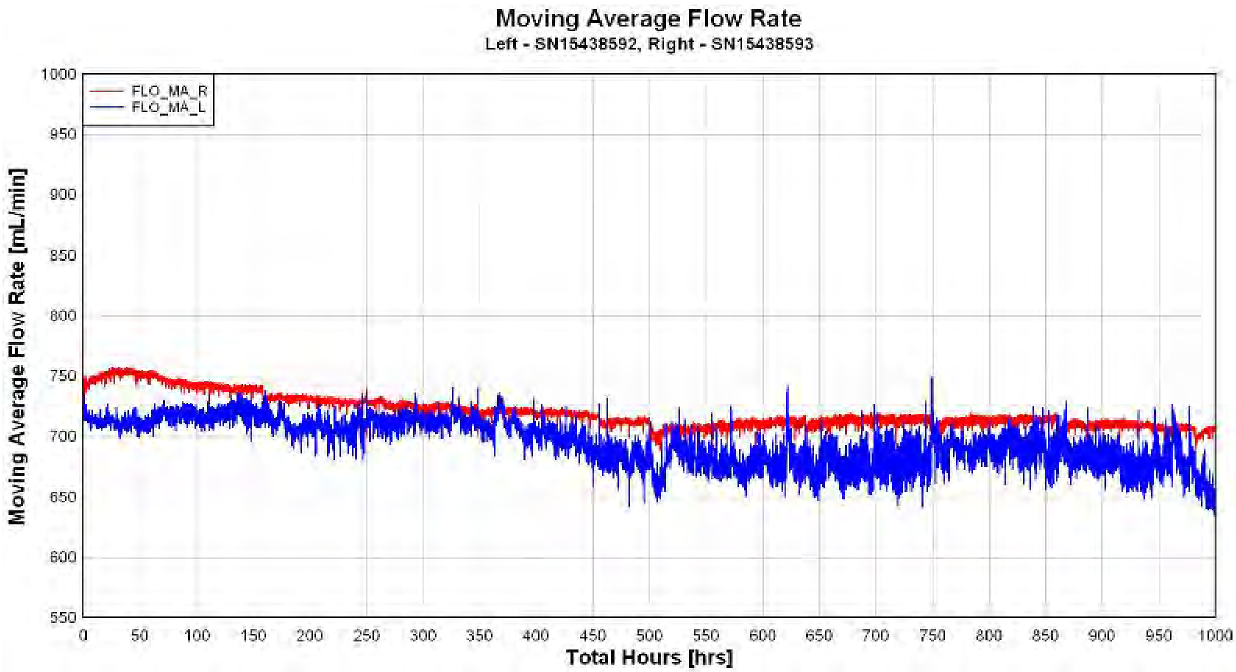


Figure K-2. Pump Flow, Moving Average

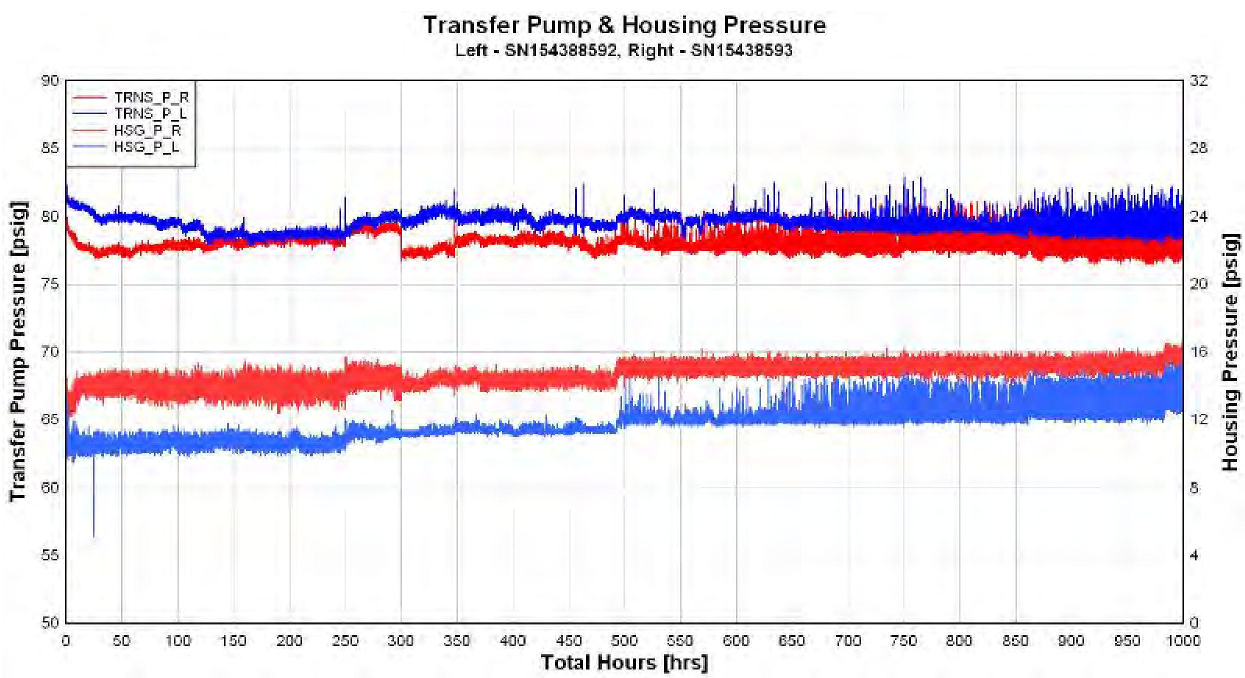


Figure K-3. Transfer Pump & Housing Pressure

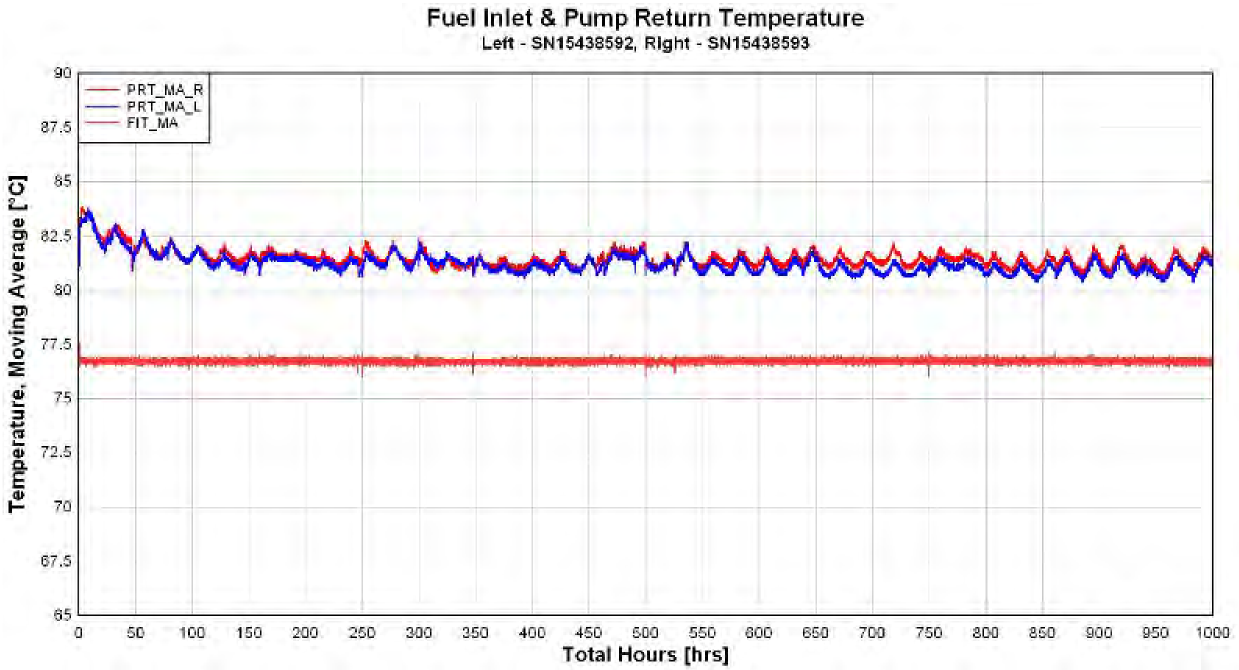


Figure K-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table K-3. (Note – Calibration data to be used as reference only).

Table K-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 11			Test Duration : 1000-hrs.		
Test Fuel :	Jet A-1 w/25-mg/L NALCO 5403 @ 170°F			SN : 15438592			SN : 15438593		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	61 psi	**55 psi**	6 psi	62 psi	**53 psi**	9 psi
	Return Fuel	225 cc	375 cc	260 cc	285 cc	-25 cc	300 cc	250 cc	50 cc
350	Low Idle	12 cc	16 cc	15 cc	**19 cc**	-4 cc	14 cc	16 cc	-2 cc
	Housing psi.	8 psi	12 psi	**6.5 psi**	**6.0 psi**	.5 psi	9.0 psi	10.0 psi	-1.0 psi
	Advance	3.50°		3.89°	**2.70°**	1.19°	5.00°	4.50°	.50°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	**12.0 cc**	-12.0 cc	.0 cc	.2 cc	-.2 cc
900	Fuel Delivery	66.5 cc	69.5 cc	**66.0 cc**	**65.0 cc**	1.0 cc	67.0 cc	**64.5 cc**	2.5 cc
1600	WOT Fuel delivery	60 cc		61 cc	60 cc	1 cc	63 cc	60 cc	3 cc
	WOT Advance	2.50°	3.50°	2.98°	2.50°	.48°	3.07°	2.40°	.67°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.5 cc	-1.5 cc	22.0 cc	22.2 cc	-.2 cc
	Face Cam Advance	5.25°	7.25°	5.80°	**7.50°**	-1.70°	6.43°	**8.60°**	-2.17°
	Low Idle	11.0°	12.0°	11.0°	**10.5°**	.5°	11.1°	**10.5°**	.6°
1825	Fuel Delivery	33 cc		38 cc	55 cc	-17 cc	39 cc	54 cc	-15 cc
1950	High Idle		15 cc	2 cc	2 cc	1 cc	2 cc	1 cc	1 cc
	Transfer pump psi.		125 psi	110 psi	98 psi	12 psi	104 psi	92 psi	12 psi
200	WOT Fuel Delivery	58 cc		59 cc	**55 cc**	4 cc	59 cc	**56 cc**	3 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		48 cc	43 cc	5 cc	48 cc	46 cc	2 cc
	Transfer pump psi.	16 psi		28 psi	17 psi	11 psi	30 psi	18 psi	12 psi
	Housing psi.	.0 psi	12 psi	7.0 psi	6 psi	1 psi	10 psi	11 psi	-1 psi
	Air Timing	-1.00°	.00°	-.50°	-1.00°	.50°	-.50°	**.50°**	-1.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table K-4 and Table K-5.

Table K-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438592	Test Number: 11	
Fuel Description : Jet A-1 w/25-mg/L NALCO 5403 @ 170°F				
	Date:	12/15/2010	11/1/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2892	3.2715	-0.0177
Measurement 2		3.2891	3.2716	-0.0175
Measurement 3		3.2891	3.2715	-0.0176
Measurement 4		3.2891	3.2715	-0.0176
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2302	3.2118	-0.0184
Measurement 2		3.2303	3.2117	-0.0186
Measurement 3		3.2302	3.2118	-0.0184
Measurement 4		3.2301	3.2117	-0.0184
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2851	3.2678	-0.0173
Measurement 2		3.2850	3.2677	-0.0173
Measurement 3		3.2851	3.2676	-0.0175
Measurement 4		3.2851	3.2677	-0.0174
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2475	3.2262	-0.0213
Measurement 2		3.2475	3.2261	-0.0214
Measurement 3		3.2475	3.2262	-0.0213
Measurement 4		3.2474	3.2263	-0.0211
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2891	3.2715	-0.0176
Transfer Pump Blade 2		3.2302	3.2118	-0.0184
Transfer Pump Blade 3		3.2851	3.2677	-0.0174
Transfer Pump Blade 4		3.2475	3.2262	-0.0213
	Roller to Roller (in)	1.9760	1.9758	-0.0002
	Eccentricity (in.)	0.0040	0.0060	0.0020
	Drive Backlash (In)	0.0045	0.0055	0.0010

Table K-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438593	Test Number: 11	
Fuel Description : Jet A-1 w/25-mg/L NALCO 5403 @ 170°F				
	Date:	12/15/2010	11/2/2011	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2332	3.2238	-0.0094
Measurement 2		3.2332	3.2238	-0.0094
Measurement 3		3.2331	3.2239	-0.0092
Measurement 4		3.2331	3.2238	-0.0093
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2725	3.2567	-0.0158
Measurement 2		3.2725	3.2567	-0.0158
Measurement 3		3.2725	3.2567	-0.0158
Measurement 4		3.2725	3.2567	-0.0158
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2732	3.2654	-0.0078
Measurement 2		3.2731	3.2656	-0.0075
Measurement 3		3.2731	3.2655	-0.0076
Measurement 4		3.2731	3.2656	-0.0075
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2702	3.2608	-0.0094
Measurement 2		3.2702	3.2607	-0.0095
Measurement 3		3.2702	3.2606	-0.0096
Measurement 4		3.2702	3.2607	-0.0095
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2332	3.2238	-0.0093
Transfer Pump Blade 2		3.2725	3.2567	-0.0158
Transfer Pump Blade 3		3.2731	3.2655	-0.0076
Transfer Pump Blade 4		3.2702	3.2607	-0.0095
	Roller to Roller (in)	1.9760	1.9741	-0.0019
	Eccentricity (in.)	0.0070	0.0090	0.0020
	Drive Backlash (In)	0.0045	0.0065	0.0020

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table K-6.

Table K-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
11	15438592	Jet A-1 w/25-mg/L NALCO 5403 @ 170°F	11-1	2175	1975	Pass	Pass	Pass	Pass	Pass	Pass
			11-2	2200	1925	Pass	Pass	Pass	Pass	Pass	Pass
			11-3	2150	1925	Pass	Pass	Pass	Pass	Pass	Pass
			11-4	2125	1975	Pass	Pass	Pass	Pass	Pass	Pass
			11-5	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			11-6	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			11-7	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			11-8	2100	1925	Pass	Pass	Pass	Pass	Pass	Pass
11	15438593	Jet A-1 w/25-mg/L NALCO 5403 @ 170°F	11-11	2225	1925	Pass	Pass	Pass	Pass	Pass	Pass
			11-12	2075	1850	Pass	Pass	Pass	Pass	Pass	Pass
			11-13	2200	1975	Pass	Pass	Pass	Pass	Pass	Pass
			11-14	2175	1875	Pass	Pass	Pass	Pass	Pass	Pass
			11-15	2125	1900	Pass	Pass	Pass	Pass	Pass	Pass
			11-16	2125	1875	Pass	Pass	Pass	Pass	Pass	Pass
			11-17	2150	1900	Pass	Pass	Pass	Pass	Pass	Pass
			11-18	2100	1925	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table A-7 and Table A-8.

Table K-7. Stanadyne Left Pump Parts Evaluation

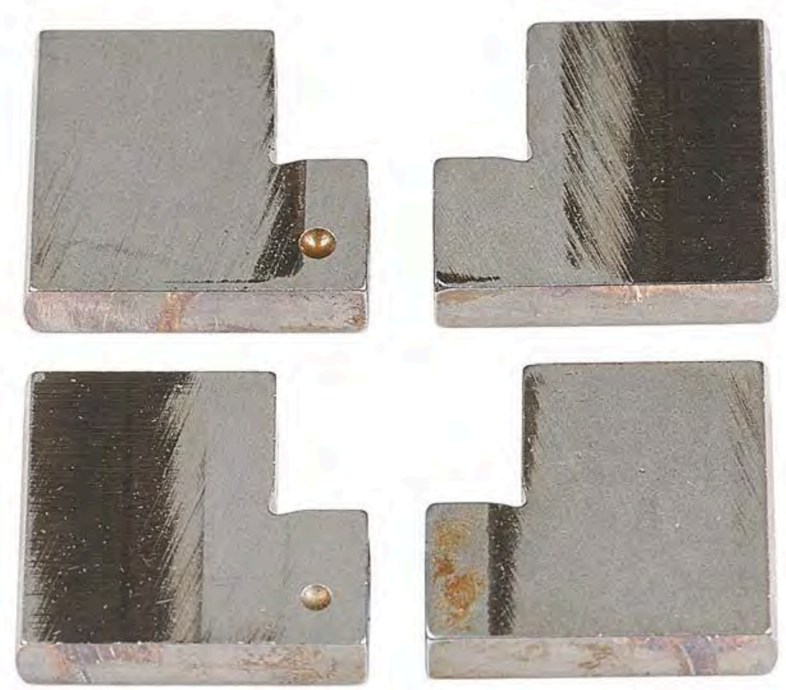
Pump Type : DB2831-5079		SN: 15438592
Test Condition : Jet A-1 w/25-mg/L NALCO 5403 @ 170°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Normal	1
LINER	80% surface scuffing wear	3.5
TRANSFER PUMP REGULATOR	Heavy deposits. Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Wear on one side of piston	2
ROTOR	Wear marks at distributor and inlet ports	1.5
ROTOR RETAINERS	Deposits. Wear from rotor contact	1.5
DELIVERY VALVE	Light polising	1
PLUNGERS	Left plunger discolored, polishing wear	2
SHOES	Light wear from contact points	1.5
ROLLERS	Light scoring	2.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Normal	1
THRUST WASHER	Polising wear from weights	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2
LINK HOOK	Normal	1
METERING VAVLE	Deposits, polishing wear	1.5
DRIVE SHAFT TANG	Polising wear.	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal in specification	1
ADVANCE PISTON	Scoring wear top right, deposits	3
HOUSING	Normal, brown deposits	1
	AVERAGE DEMERIT RATINGS	1.609

Table K-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438593
Test Condition : Jet A-1 w/25-mg/L NALCO 5403 @ 170°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Normal	1
LINER	80% surface scuffing wear	3.5
TRANSFER PUMP REGULATOR	Heavy deposits. Wear mark from rotor, light polishing	2
REGULATOR PISTON	Wear on one side of piston	2
ROTOR	Wear marks at distributor and inlet ports	2.5
ROTOR RETAINERS	Deposits. Wear from rotor contact	2
DELIVERY VALVE	Light polising	1
PLUNGERS	Left plunger discolored, polishing wear	2
SHOES	Light wear from contact points	2
ROLLERS	Light scoring	2
LEAF SPRING	Wear from shoe contact	2
CAM RING	Normal	2
THRUST WASHER	Polising wear from weights	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	1
LINK HOOK	Normal	2
METERING VAVLE	Deposits, polishing wear	2
DRIVE SHAFT TANG	Polising wear.	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal in specification	1
ADVANCE PISTON	Scoring wear top right, deposits	3
HOUSING	Normal, brown deposits	1
	AVERAGE DEMERIT RATINGS	1.761

PHOTOGRAPHS FOR LEFT PUMP

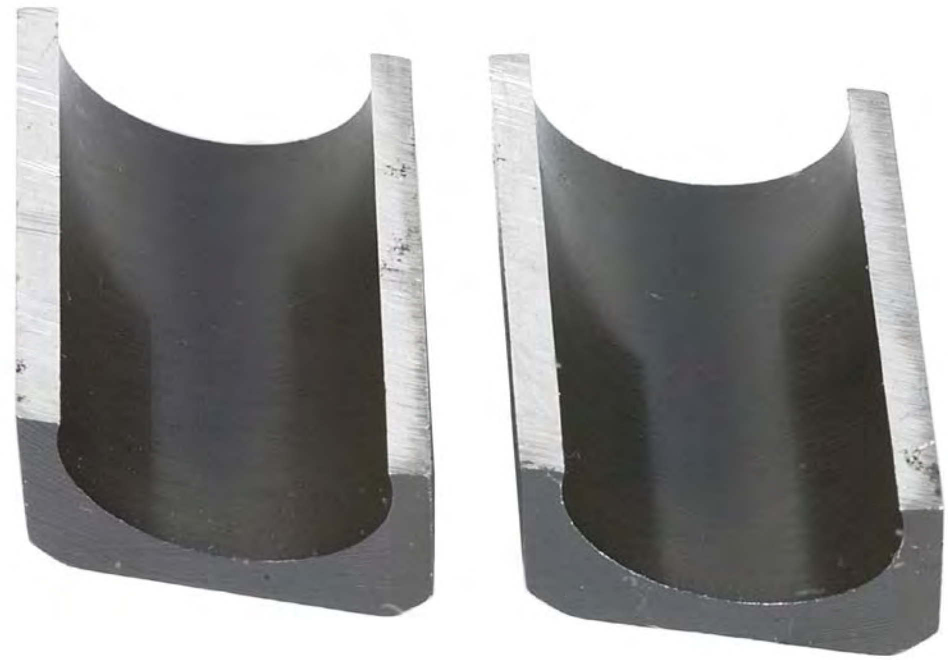
SN15438592 Transfer Pump Blades (Side), Before



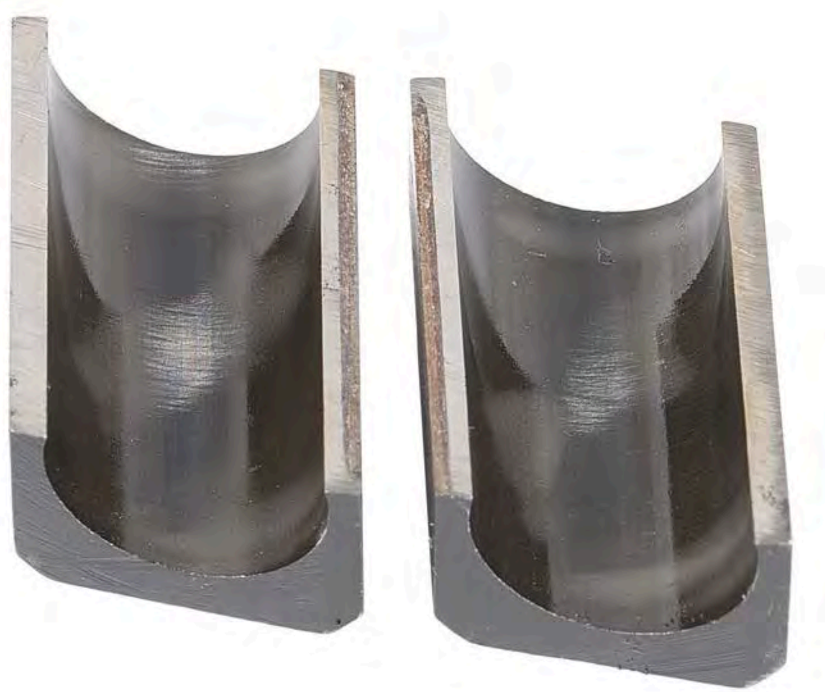
SN15438592 Transfer Pump Blades (Side), After

SN15438592 Transfer Pump Blades (Profile), Before

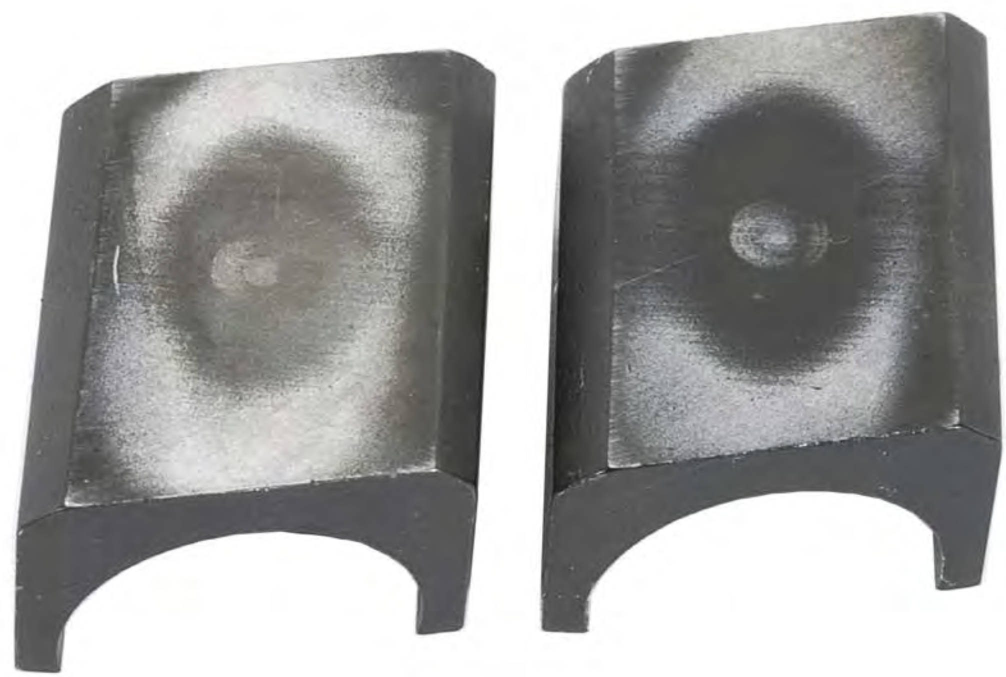
SN15438592 Transfer Pump Blades (Profile), After



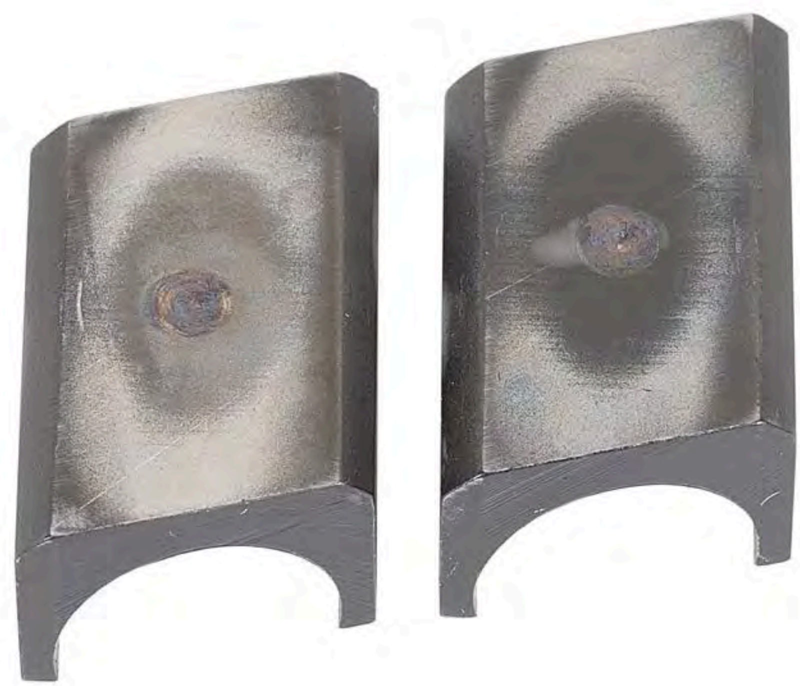
SN15438592 Shoes (Front), Before



SN15438592 Shoes (Front), After



SN15438592 Shoes (Back), Before



SN15438592 Shoes (Back), After

SN15438592 Rollers, Before

SN15438592 Rollers, After

SN15438592 Piston Plungers, Before

SN15438592 Piston Plungers, After

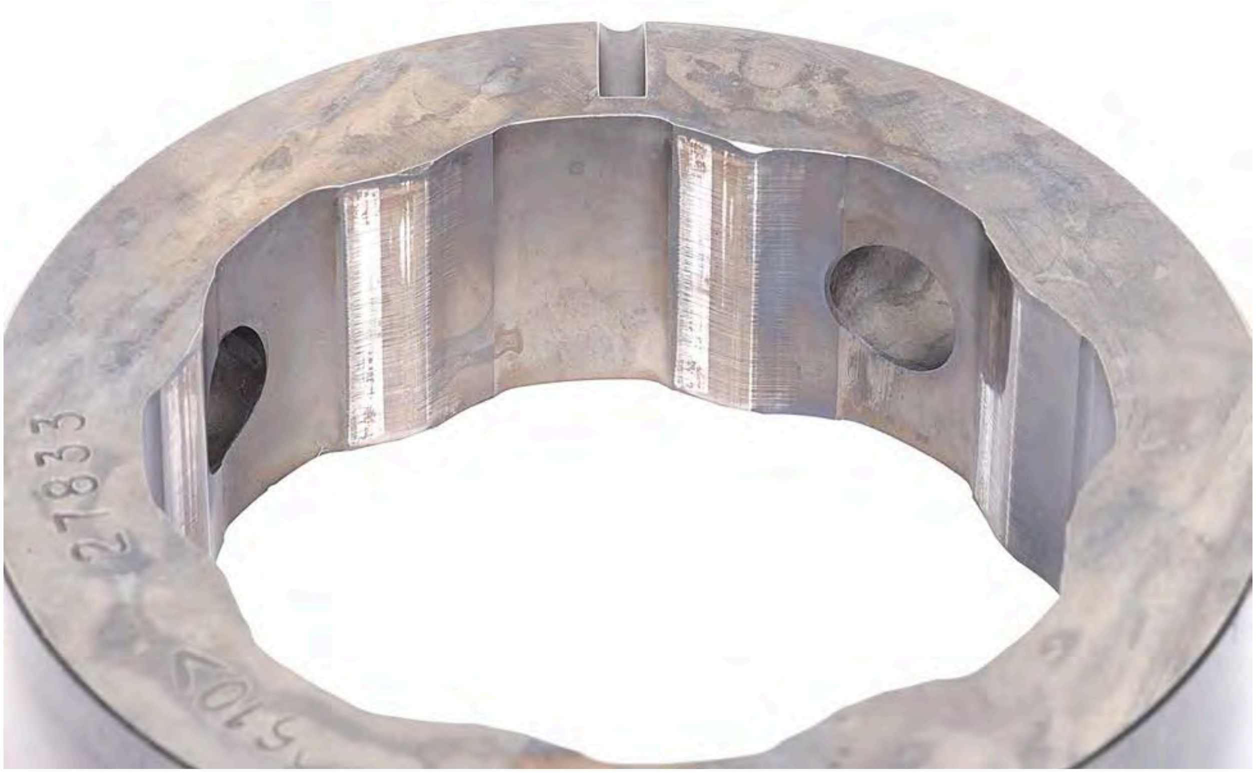
SN15438592 Thrust Washer, Before

SN15438592 Thrust Washer, After

SN15438592 Governor Weight, Before

SN15438592 Governor Weight, After

SN15438592 **Cam Ring, Before**



SN15438592 Cam Ring, After

SN15438592 Eccentric Ring, Before

SN15438592 Eccentric Ring, After

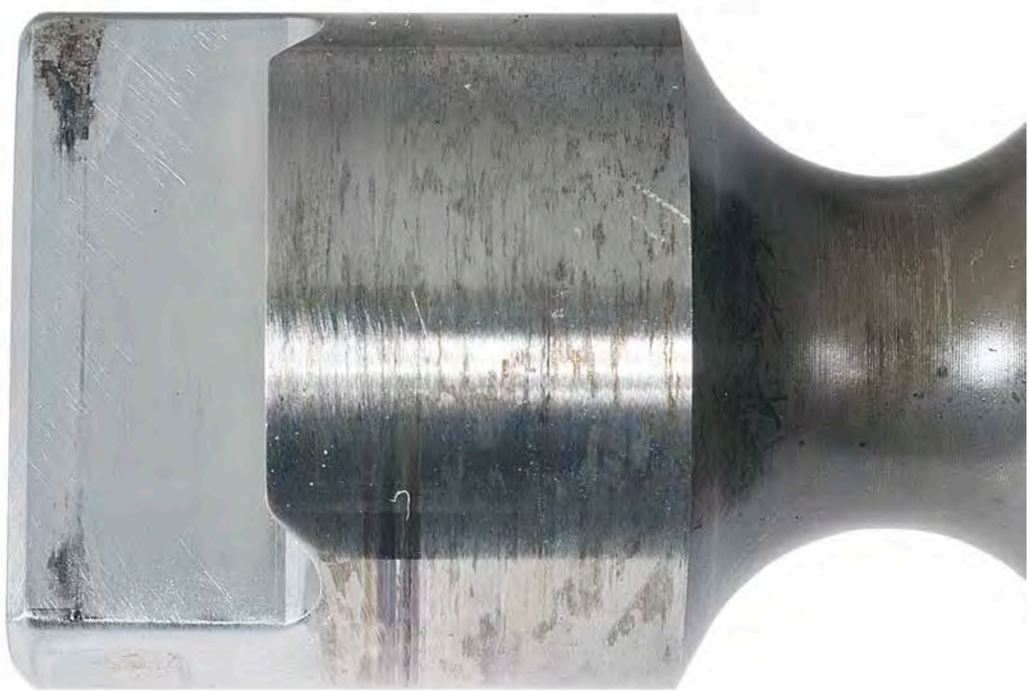
SN15438592 Rotor (Front), Before

SN15438592 Rotor (Front), After

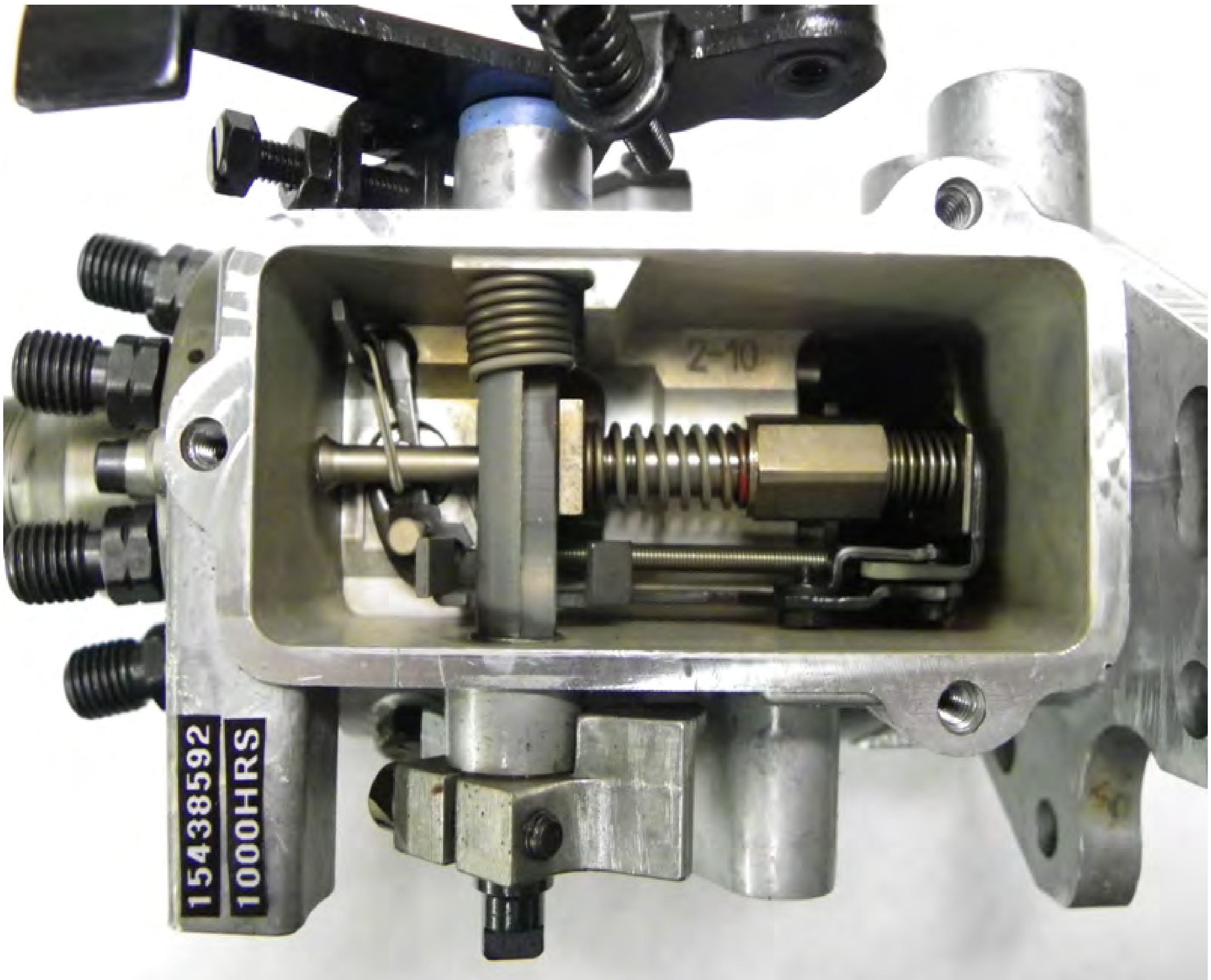
SN15438592 Rotor (Back), Before

SN15438592 Rotor (Back), After

SN15438592 Drive Tang, Before

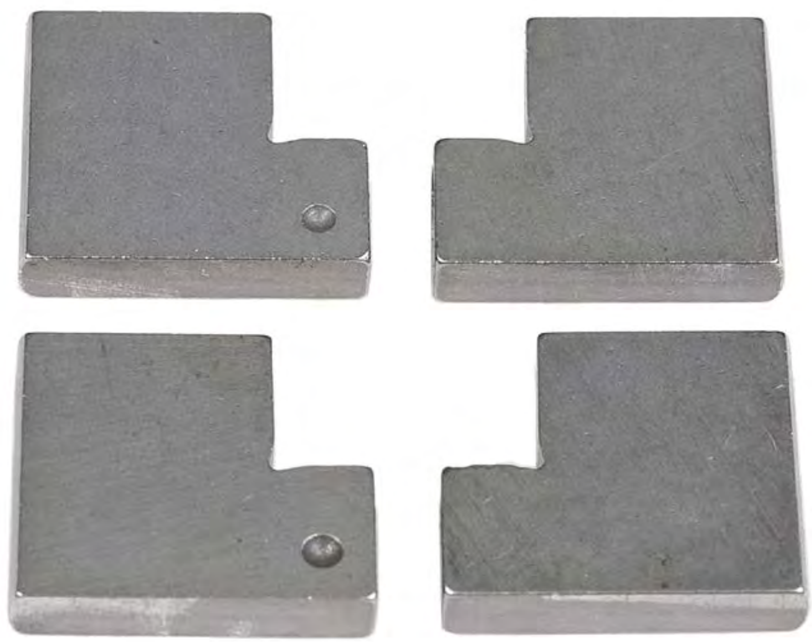


SN15438592 Drive Tang, After

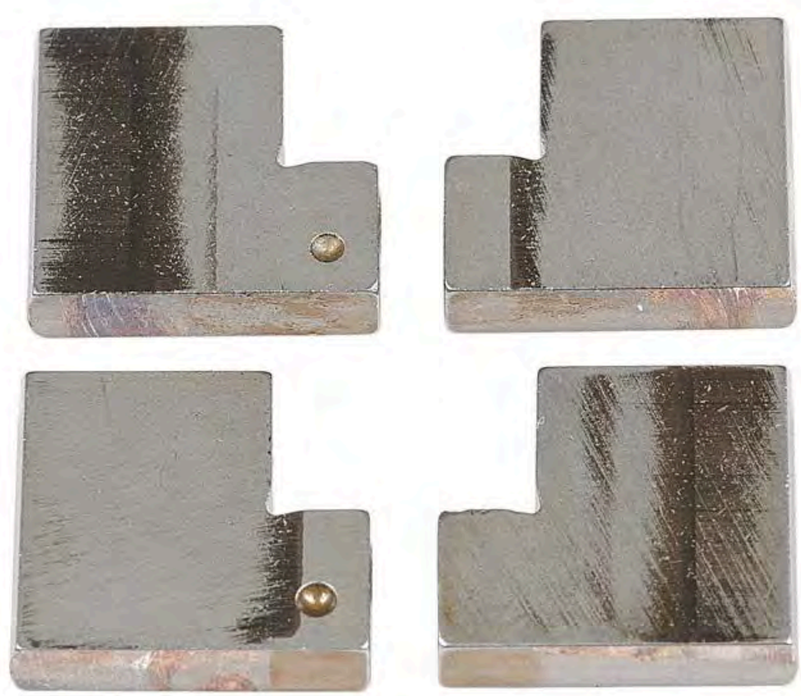


SN15438592 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



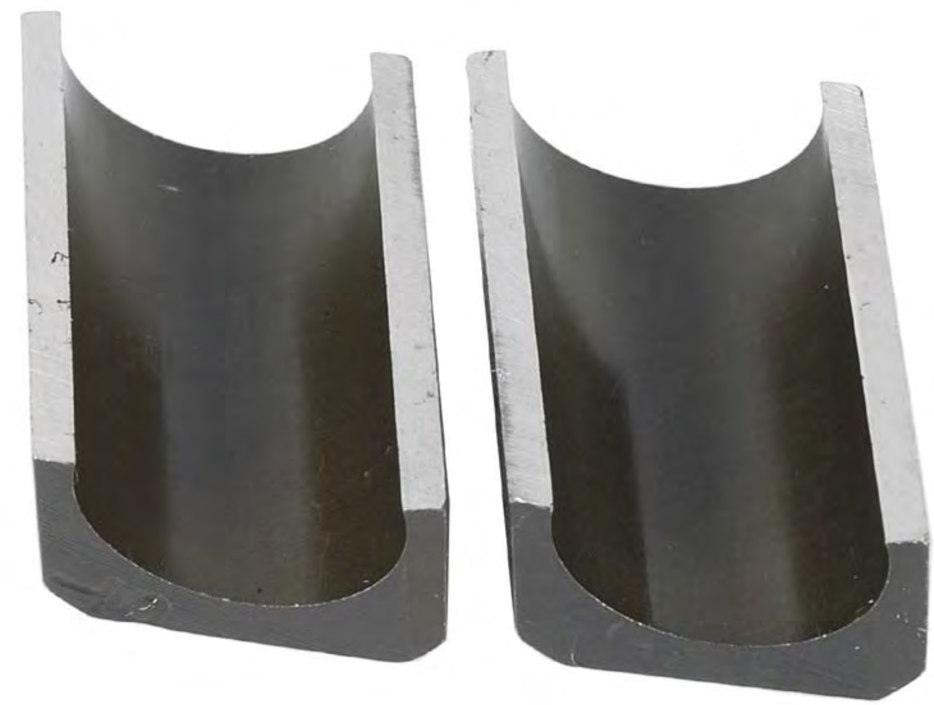
SN15438593 Transfer Pump Blades, Before



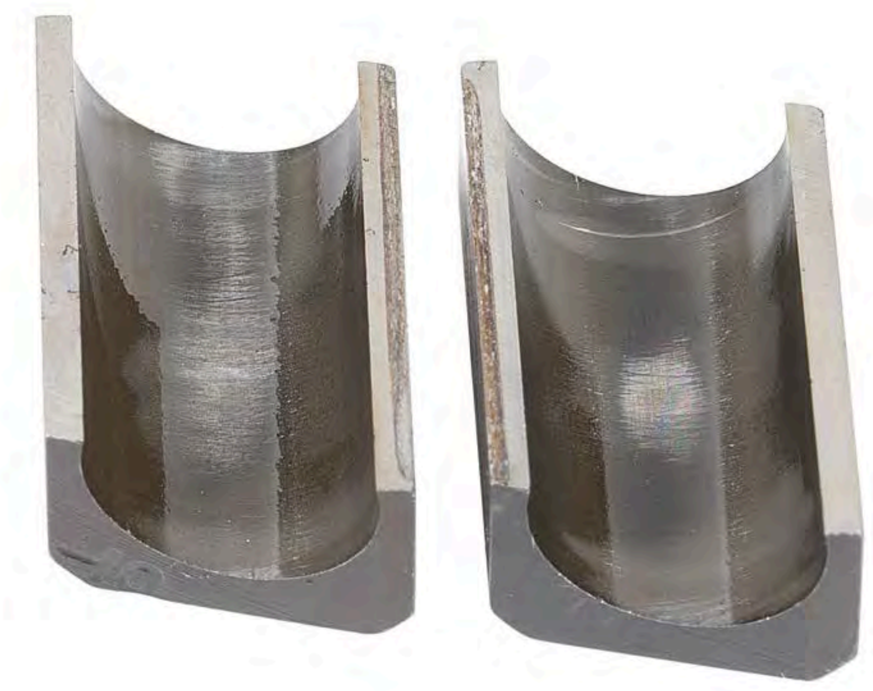
SN15438593 Transfer Pump Blades, After

SN15438593 Transfer Pump Blades (Profile), Before

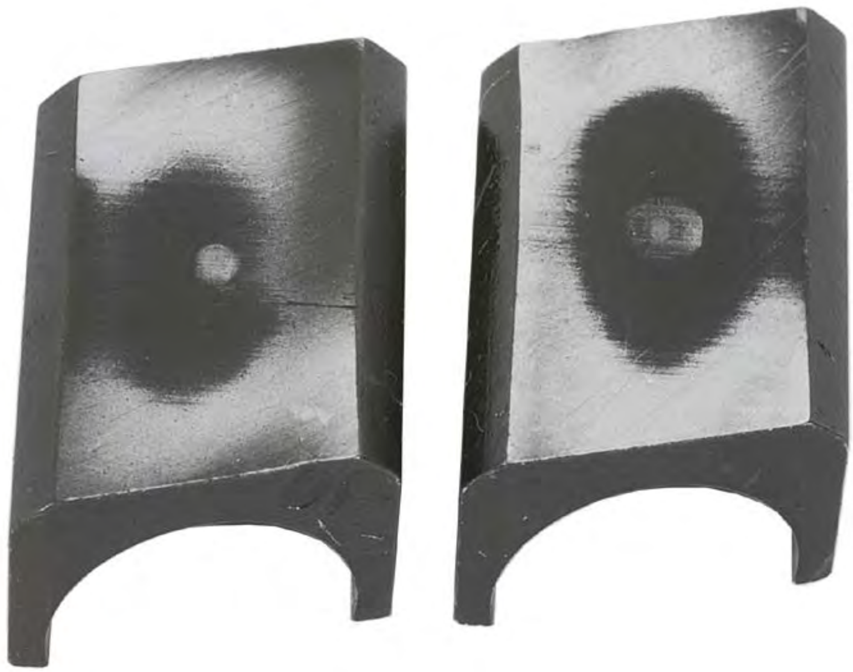
SN15438593 Transfer Pump Blades (Profile), After



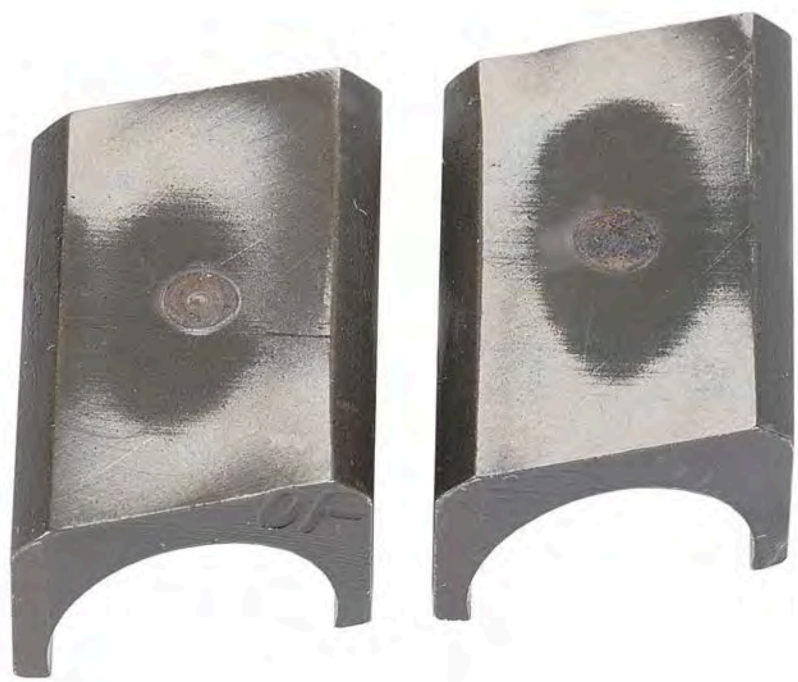
SN15438593 Shoes (Front), Before



SN15438593 Shoes (Front), After



SN15438593 Shoes (Back), Before



SN15438593 Shoes (Back), After

SN15438593 Rollers, Before

SN15438593 Rollers, After

SN15438593 Piston Plungers, Before

SN15438593 Piston Plungers, After

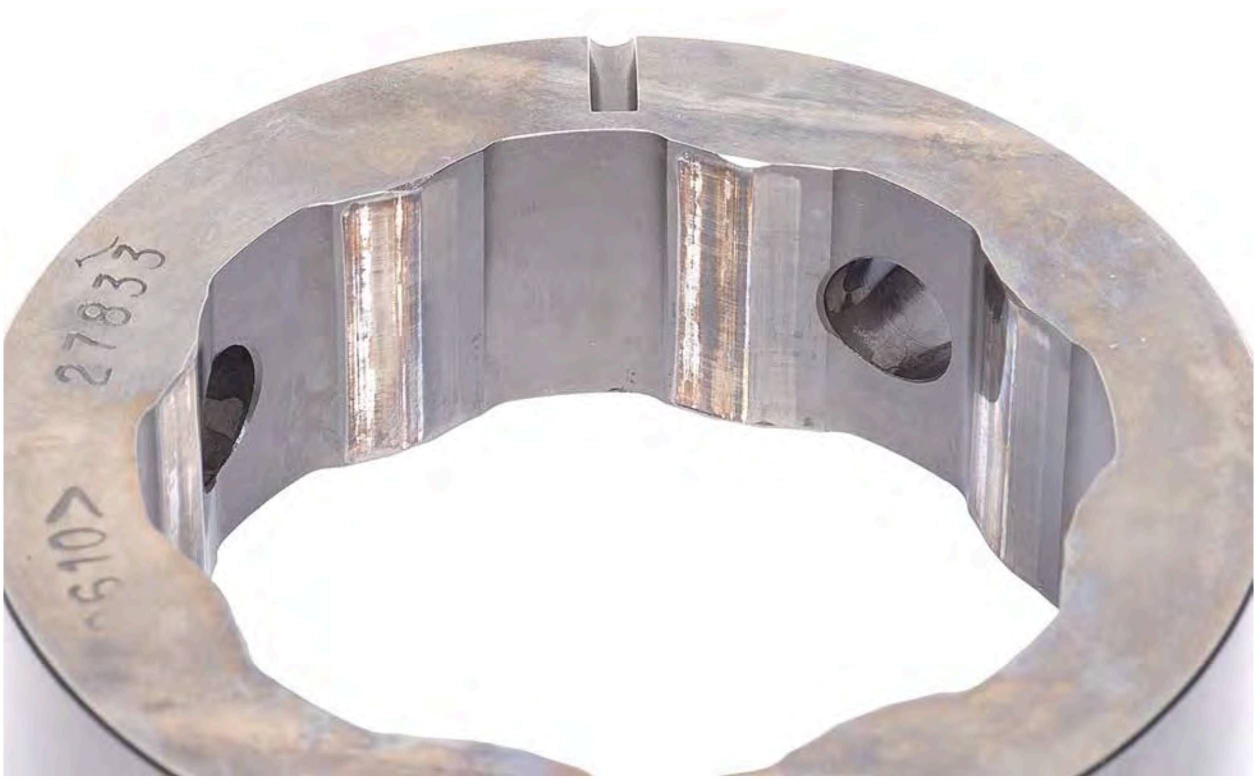
SN15438593 Thrust Washer, Before

SN15438593 Thrust Washer, After

SN15438593 Governor Weight, Before

SN15438593 Governor Weight, After

SN15438593 Cam Ring, Before



SN15438593 Cam Ring, After

SN15438593 Eccentric Ring, Before

SN15438593 Eccentric Ring, After

SN15438593 Rotor (Front), Before

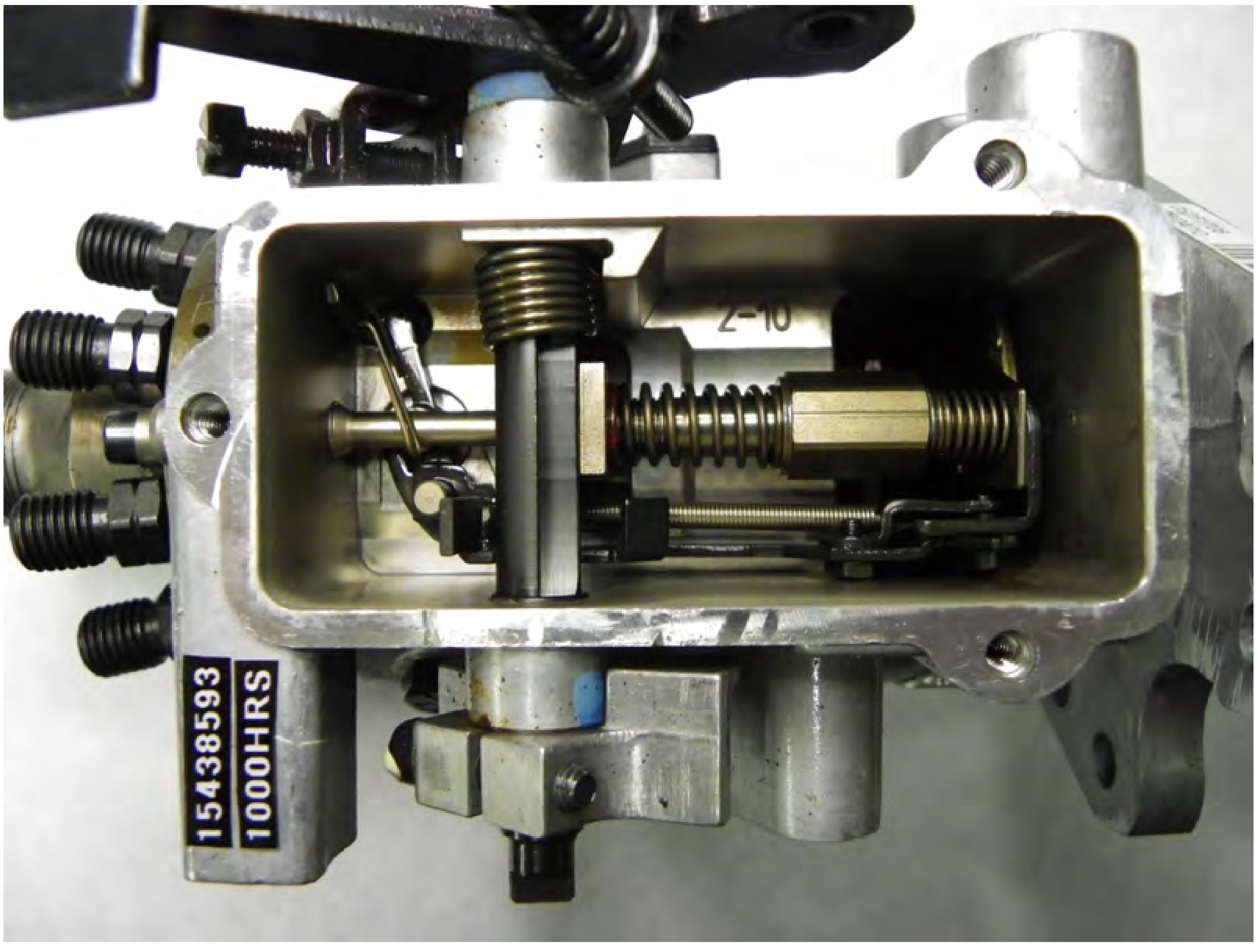
SN15438593 Rotor (Front), After

SN15438593 Rotor (Back), Before

SN15438593 Rotor (Back), After

SN15438593 Drive Tang, Before

SN15438593 Drive Tang, After



SN15438593 Governor Assembly

APPENDIX L

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 50-mg/L INNOSPEC OLI 9070x
Test Number: AF7090-C3T12-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 50-mg/L INNOSPEC OLI 9070x
Test Fuel ID: AF7090
Test Temperature: 40°C (105°F)
Test Number: AF7090-C3T12-40-1000
Start of Test Date: August 17, 2011
End of Test Date: October20, 2011
Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure 1.

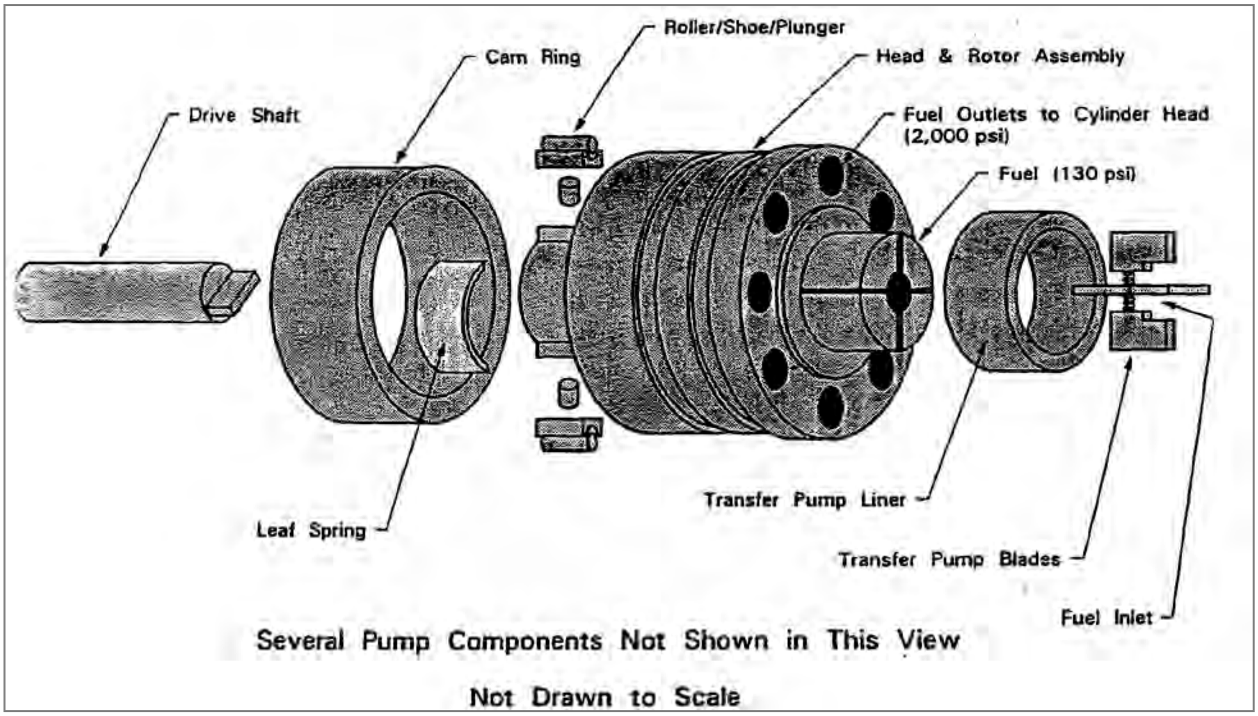


Figure L-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table L-1.

Table L-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table L-2.

Table L-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.0416
FLO_R	Injected Flow-rate [mL/min]	813.6	15.9
FUELIN_P	Fuel Inlet Pressure [psig]	2.7	0.482
TRNS_P_R	Transfer Pump Pressure [psig]	75.5	1.10
HSG_P_R	Pump Housing Pressure [psig]	10.6	.25
RTRN_T_R	Fuel Return Temperature [°C]	48.9	1.54
FUEL_T	Fuel Tank Temperature [°C]	30.3	1.7
FUELIN_T	Fuel Inlet Temperature [°C]	40	0.64

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure L-2 through Figure L-4.

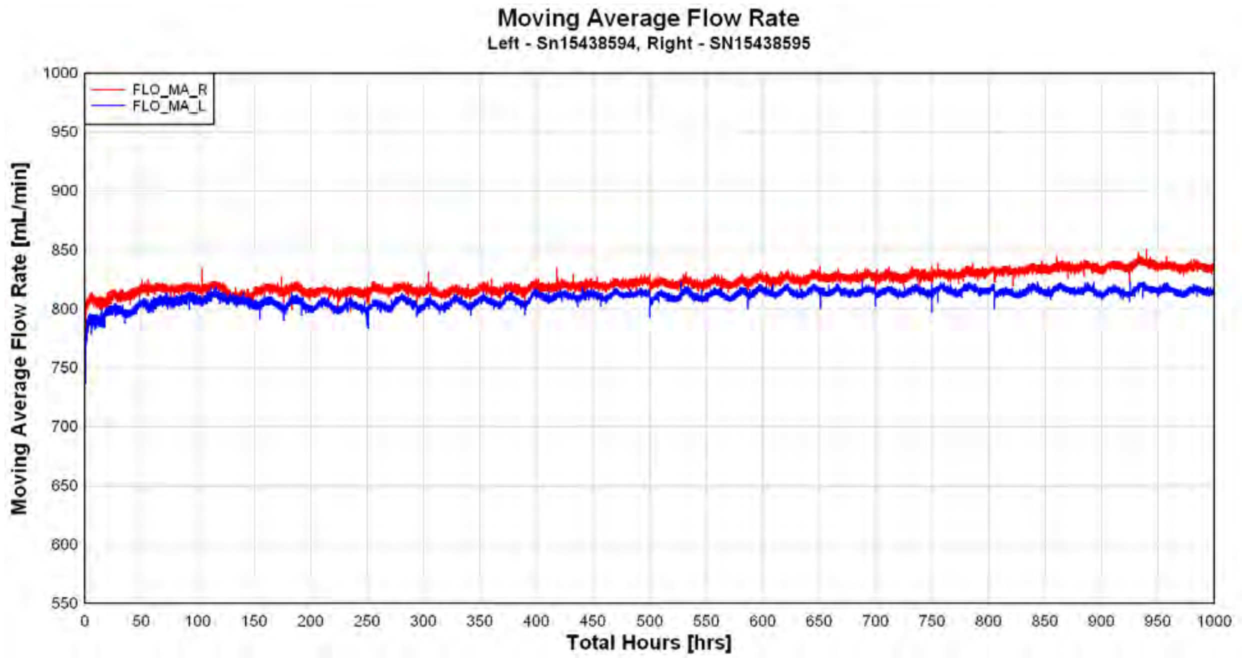


Figure L-2. Pump Flow, Moving Average

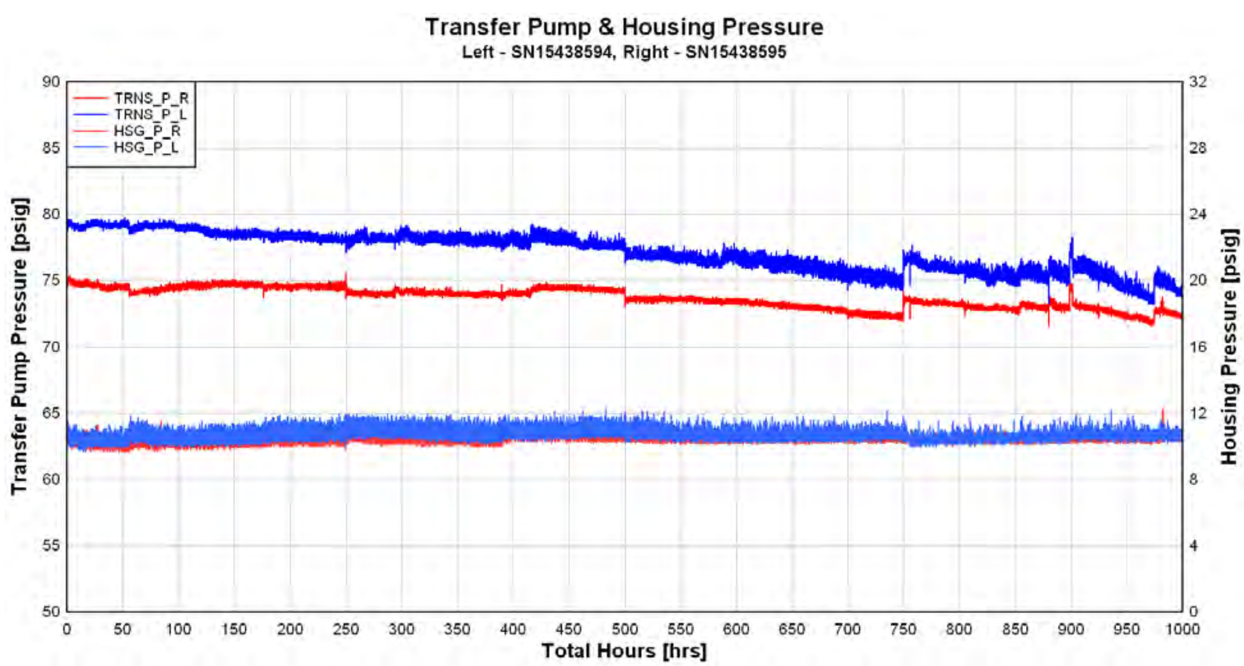


Figure L-3. Transfer Pump & Housing Pressure

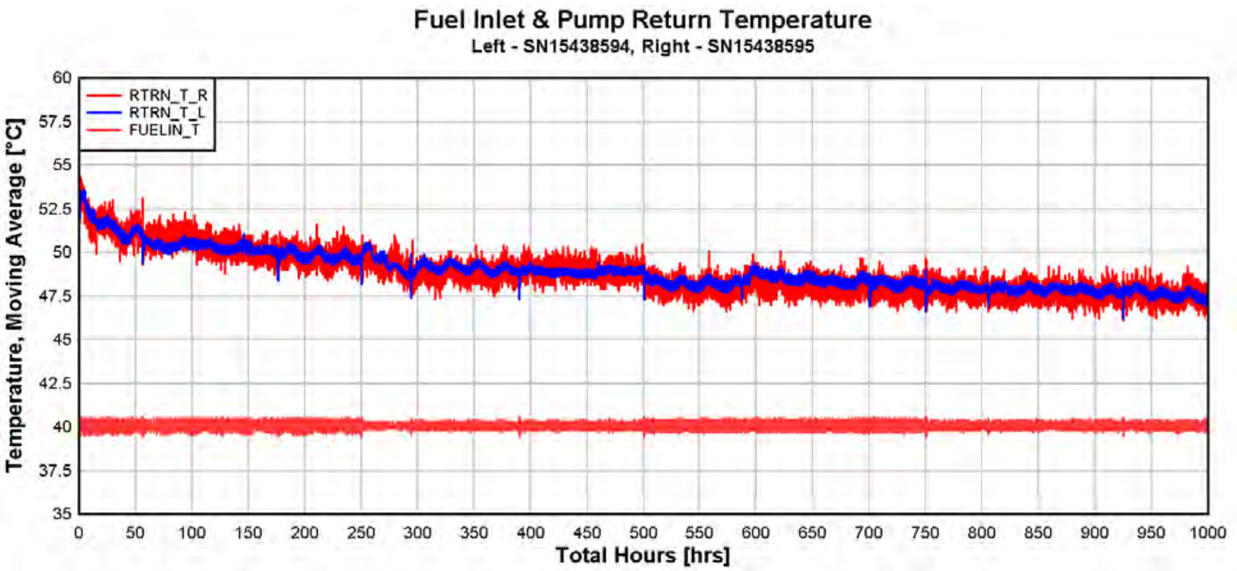


Figure L-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table L-3. (Note – Calibration data to be used as reference only)

Table L-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 12			Test Duration : 1000-hrs.		
Test Fuel : Jet A-1 w/50-mg/L OLI-9070x @ 105°F				SN : 15438594			SN : 15438595		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	60 psi	62 psi	-2 psi	62 psi	**64 psi**	-2 psi
	Return Fuel	225 cc	375 cc	290 cc	234 cc	56 cc	334 cc	**400 cc**	-66 cc
350	Low Idle	12 cc	16 cc	14 cc	**20 cc**	-6 cc	16 cc	**10 cc**	6 cc
	Housing psi.	8 psi	12 psi	8.0 psi	9.5 psi	-1.5 psi	9.5 psi	10.0 psi	-.5 psi
	Advance	3.50°		4.55°	4.43°	.12°	5.62°	5.05°	.57°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.5 psi	.0 psi	.5 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	68.0 cc	-1.0 cc	67.0 cc	67.0 cc	.0 cc
1600	WOT Fuel delivery	60 cc		62 cc	64 cc	-2 cc	62 cc	63 cc	-1 cc
	WOT Advance	2.50°	3.50°	3.00°	2.72°	.28°	5.02°	4.92°	.10°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.15°	6.37°	-.22°	6.97°	6.76°	.21°
	Low Idle	11.0°	12.0°	11.0°	11.1°	-.1°	11.1°	11.1°	.0°
1825	Fuel Delivery	33 cc		40 cc	62 cc	-22 cc	39 cc	60 cc	-21 cc
1950	High Idle		15 cc	3 cc	2 cc	1 cc	6 cc	10 cc	-4 cc
	Transfer pump psi.		125 psi	107 psi	109 psi	-2 psi	107 psi	105 psi	2 psi
200	WOT Fuel Delivery	58 cc		60 cc	60 cc	0 cc	61 cc	68 cc	-7 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		48 cc	48 cc	cc	52 cc	47 cc	5 cc
	Transfer pump psi.	16 psi		31 psi	25 psi	6 psi	24 psi	21 psi	3 psi
	Housing psi.	.0 psi	12 psi	7.0 psi	8 psi	-1 psi	6 psi	9 psi	-3 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table L-4 and Table L-5.

Table L-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438594	Test Number: 12	
Fuel Description : Jet A-1 w/50-mg/L OLI-9070x @ 105°F				
	Date:	3/4/2011	1/19/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2865	3.2870	0.0005
Measurement 2		3.2865	3.2868	0.0003
Measurement 3		3.2866	3.2869	0.0003
Measurement 4		3.2866	3.2869	0.0003
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2778	3.2799	0.0021
Measurement 2		3.2778	3.2799	0.0021
Measurement 3		3.2779	3.2799	0.0020
Measurement 4		3.2781	3.2798	0.0017
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2188	3.2190	0.0002
Measurement 2		3.2189	3.2191	0.0002
Measurement 3		3.2189	3.2190	0.0001
Measurement 4		3.2187	3.2191	0.0004
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2712	3.2731	0.0019
Measurement 2		3.2713	3.2731	0.0018
Measurement 3		3.2713	3.2731	0.0018
Measurement 4		3.2713	3.2731	0.0018
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2866	3.2869	0.0004
Transfer Pump Blade 2		3.2779	3.2799	0.0020
Transfer Pump Blade 3		3.2188	3.2191	0.0002
Transfer Pump Blade 4		3.2713	3.2731	0.0018
	Roller to Roller (in)	1.9760	1.9773	0.0013
	Eccentricity (in.)	0.0100	0.0140	0.0040
	Drive Backlash (In)	0.0040	0.0070	0.0030

Table L-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438595	Test Number: 12	
Fuel Description : Jet A-1 w/50-mg/L OLI-9070x @ 105°F				
	Date:	3/4/2011	1/19/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2615	3.2622	0.0007
Measurement 2		3.2615	3.2623	0.0008
Measurement 3		3.2616	3.2624	0.0008
Measurement 4		3.2616	3.2625	0.0009
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2557	3.2526	-0.0031
Measurement 2		3.2556	3.2536	-0.0020
Measurement 3		3.2556	3.2524	-0.0032
Measurement 4		3.2557	3.2525	-0.0032
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2652	3.2654	0.0002
Measurement 2		3.2651	3.2653	0.0002
Measurement 3		3.2650	3.2652	0.0002
Measurement 4		3.2650	3.2652	0.0002
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2341	3.2309	-0.0032
Measurement 2		3.2340	3.2310	-0.0030
Measurement 3		3.2340	3.2310	-0.0030
Measurement 4		3.2340	3.2310	-0.0030
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2616	3.2624	0.0008
Transfer Pump Blade 2		3.2557	3.2528	-0.0029
Transfer Pump Blade 3		3.2651	3.2653	0.0002
Transfer Pump Blade 4		3.2340	3.2310	-0.0031
	Roller to Roller (in)	1.9760	1.9768	0.0008
	Eccentricity (in.)	0.0120	0.0150	0.0030
	Drive Backlash (In)	0.0050	0.0100	0.0050

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table L-6.

Table L-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
12	15438594	Jet A-1 w/50-mg/L OLI-9070x @ 105°F	12-1	2100	1675	Pass	Fail	Pass	Pass	Pass	Pass
			12-2	2100	1475	Pass	Fail	Pass	Pass	Pass	Pass
			12-3	2125	1625	Pass	Pass	Pass	Pass	Pass	Pass
			12-4	2150	1625	Pass	Pass	Pass	Pass	Pass	Pass
			12-5	2175	1750	Pass	Pass	Pass	Pass	Pass	Pass
			12-6	2125	1625	Pass	Pass	Pass	Pass	Pass	Pass
			12-7	2125	1675	Pass	Pass	Pass	Pass	Pass	Pass
			12-8	2125	1675	Pass	Pass	Pass	Pass	Pass	Pass
12	15438595	Jet A-1 w/50-mg/L OLI-9070x @ 105°F	12-11	2150	1675	Pass	Pass	Pass	Pass	Pass	Pass
			12-12	2100	1600	Pass	Pass	Pass	Pass	Pass	Pass
			12-13	2125	1700	Pass	Pass	Pass	Pass	Pass	Pass
			12-14	2100	1600	Pass	Pass	Pass	Pass	Pass	Pass
			12-15	2175	1700	Pass	Pass	Pass	Pass	Pass	Pass
			12-16	2125	1600	Pass	Pass	Pass	Pass	Pass	Pass
			12-17	2050	1700	Pass	Pass	Pass	Pass	Pass	Pass
			12-18	2100	1675	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 14 out of 16								

Comments : ______________________________

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table L-7 and Table L-8.

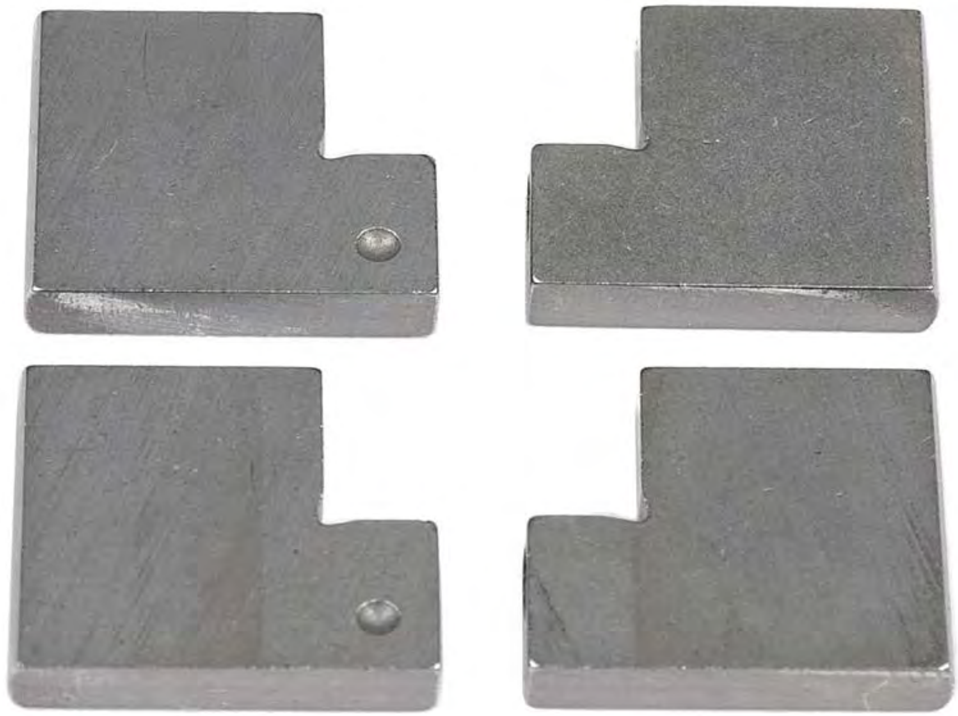
Table L-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438594
Test Condition : Jet A-1 w/50-mg/L OLI-9070x @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at roller slots and liner contact	2
BLADE SPRINGS	Rubbing wear	1
LINER	Wear on 40% of liner	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor	1.5
REGULATOR PISTON	Polishing wear on two spots	1.5
ROTOR	Heavy wear marks along distributor ports	3
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Polishing wear	2
SHOES	Dimple on back, wear from leaf spring	2.5
ROLLERS	Light pitting and discoloration	2.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Wear marks from rollers.	1
THRUST WASHER	Wear from weights. Slight groove	2
THRUST SLEEVE	Light wearfrom governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact thrust washer	2
LINK HOOK	Normal	1
METERING VAVLE	Light polishing wear	1
DRIVE SHAFT TANG	Light polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal in spec	1
ADVANCE PISTON	Scuffing wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.717

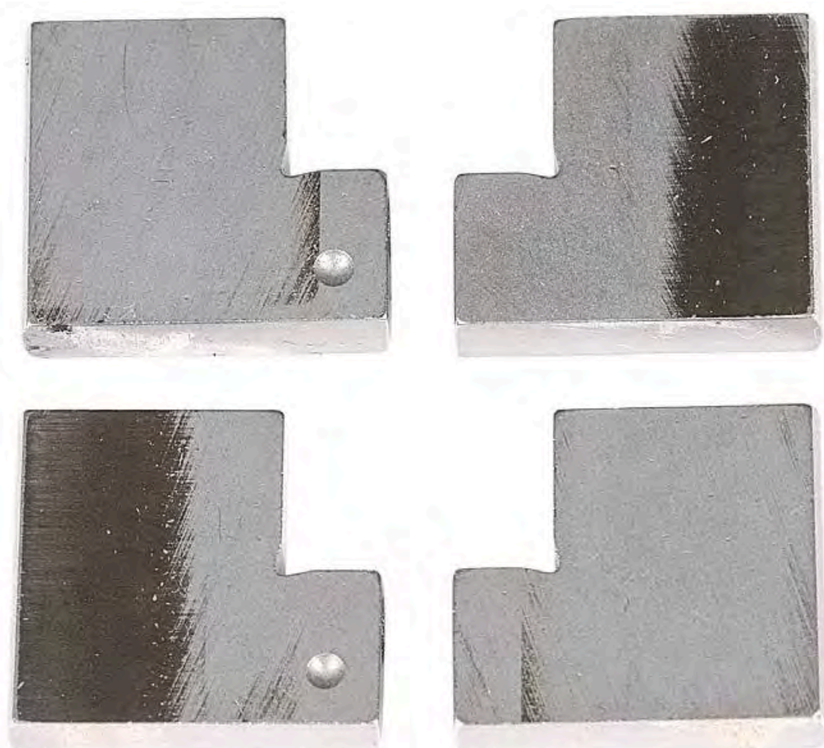
Table L-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438595
Test Condition : Jet A-1 w/50-mg/L OLI-9070x @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at roller slots and liner contact	2
BLADE SPRINGS	Rubbing wear	1
LINER	Wear on 40% of liner	3
TRANSFER PUMP REGULATOR	Wear mark from rotor	1.5
REGULATOR PISTON	Polishing wear on two spots	1.5
ROTOR	Polishing wear at distibutor ports	2.5
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Broken spring. Polishing wear	2
PLUNGERS	Polishing wear	1
SHOES	Dimple on back, wear from leaf spring	2
ROLLERS	Light pitting and discoloration	2.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Wear marks from rollers.	1
THRUST WASHER	Wear from weights. Slight groove	2
THRUST SLEEVE	Light wearfrom governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact thrust washer	2
LINK HOOK	Normal	1
METERING VAVLE	Light polishing wear	1
DRIVE SHAFT TANG	Light polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal in spec	1
ADVANCE PISTON	Scuffing wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.652

PHOTOGRAPHS FOR LEFT PUMP



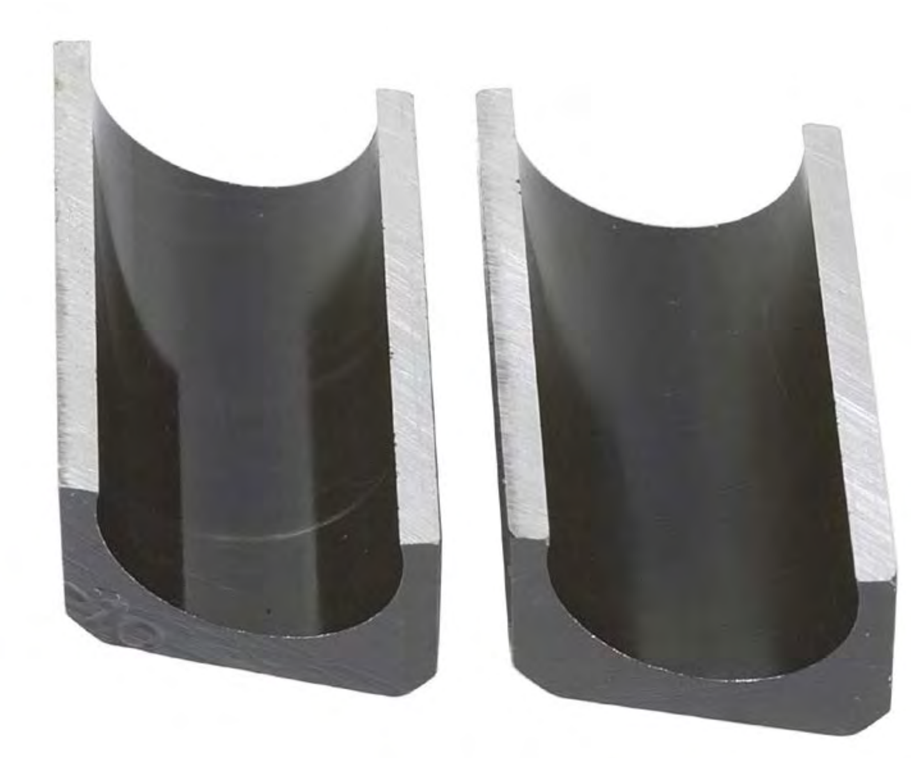
SN15438594 Transfer Pump Blades (Side), Before



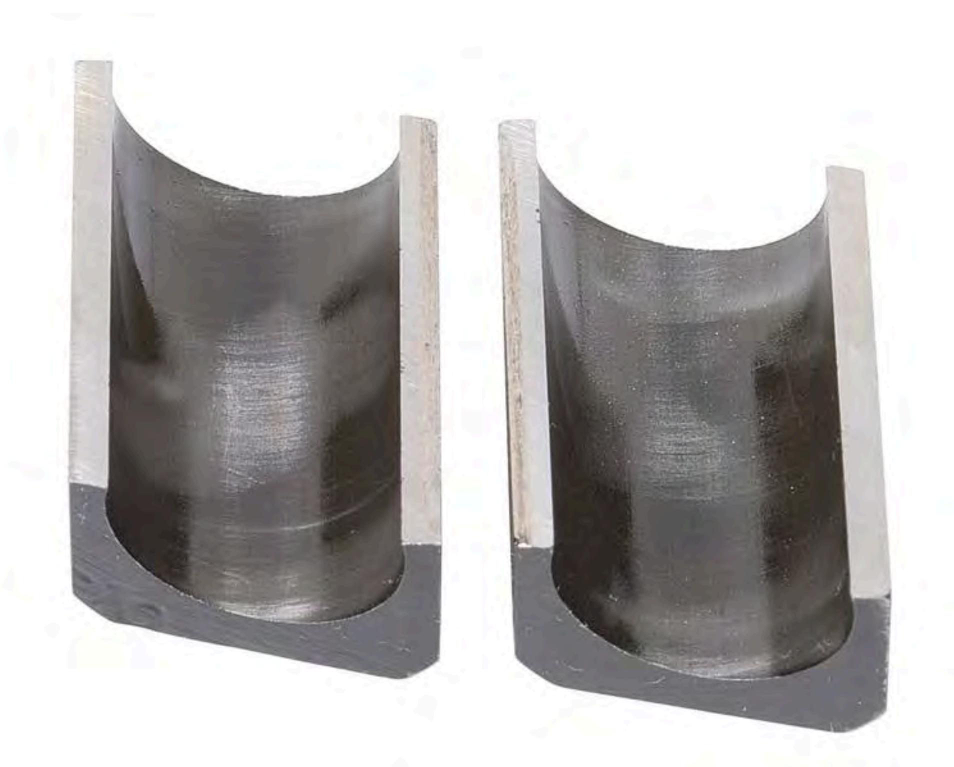
SN15438594 Transfer Pump Blades (Side), After

SN15438594 Transfer Pump Blades (Profile), Before

SN15438594 Transfer Pump Blades (Profile), After

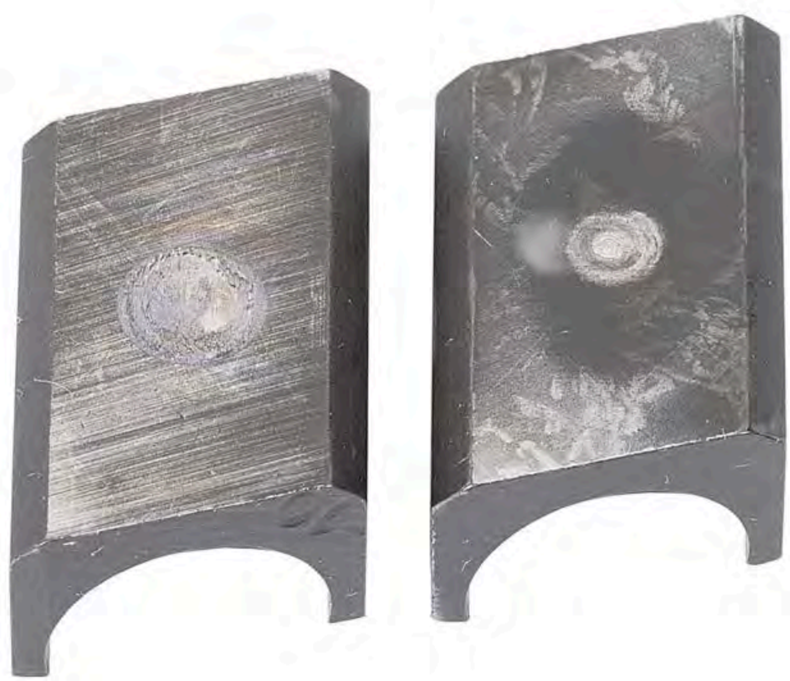


SN15438594 Shoes (Front), Before



SN15438594 Shoes (Front), After

SN15438594 Shoes (Back), Before



SN15438594 Shoes (Back), After

SN15438594 Rollers, Before

SN15438594 Rollers, After

SN15438594 Piston Plungers, Before

SN15438594 Piston Plungers, After

SN15438594 Thrust Washer, Before

SN15438594 Thrust Washer, After

SN15438594 Governor Weight, Before

SN15438594 Governor Weight, After

SN15438594 Cam Ring, Before

SN15438594 Cam Ring, After

SN15438594 Eccentric Ring, Before

SN15438594 Eccentric Ring, After

SN15438594 Rotor (Front), Before

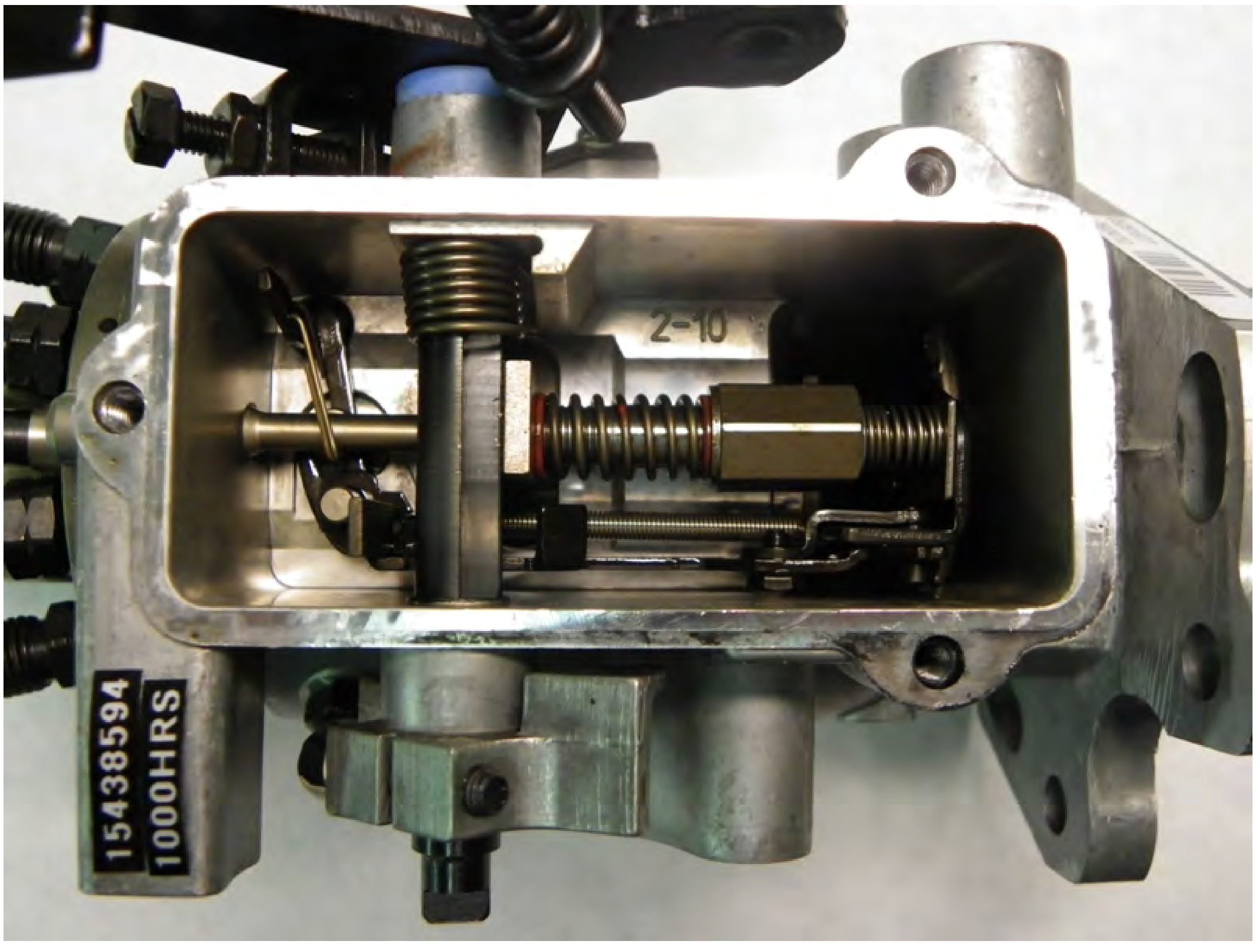
SN15438594 Rotor (Front), After

SN15438594 Rotor (Back), Before

SN15438594 Rotor (Back), After

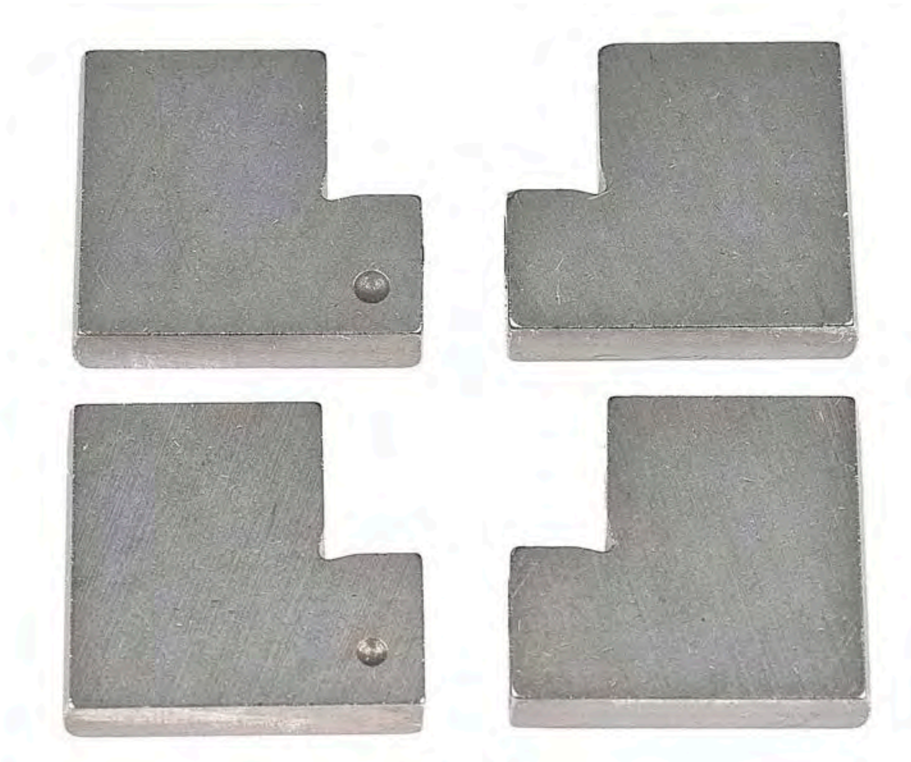
SN15438594 Drive Tang, Before

SN15438594 Drive Tang, After

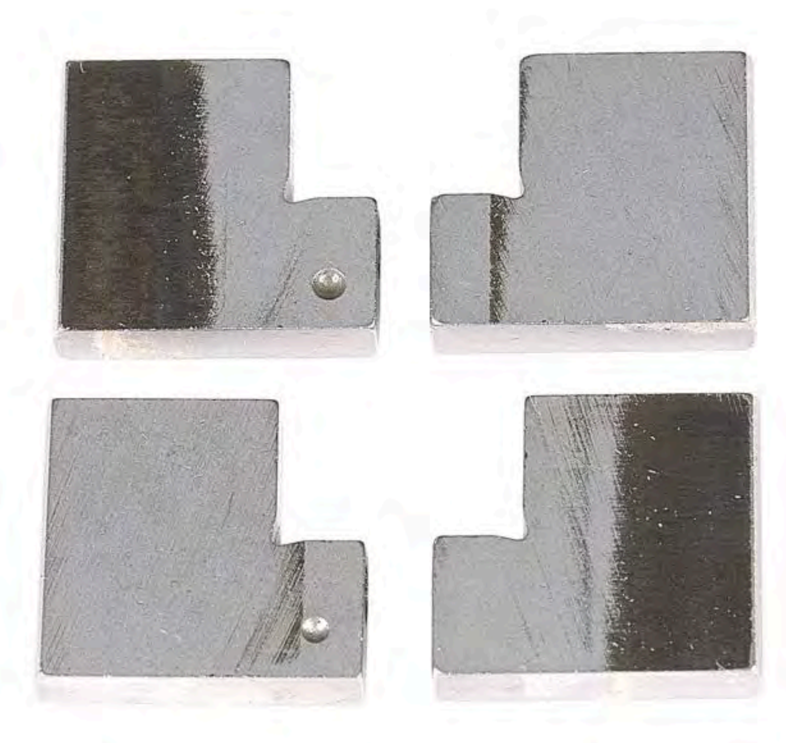


SN15438594 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



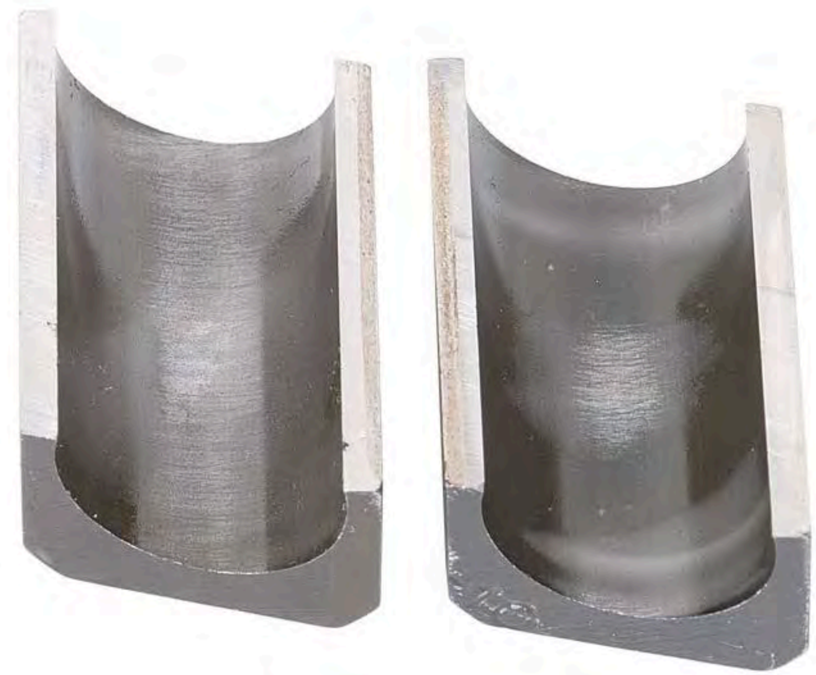
SN15438595 Transfer Pump Blades, Before



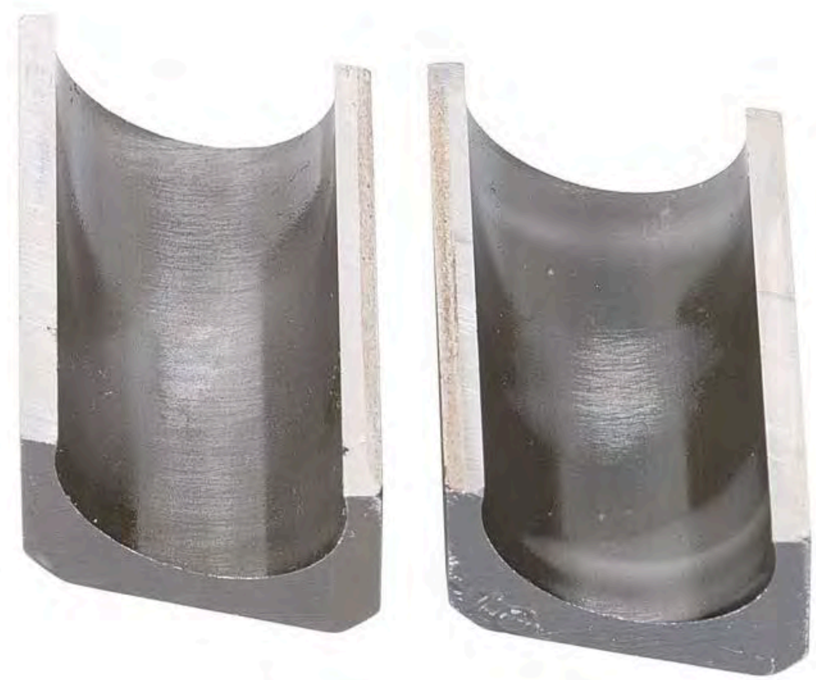
SN15438595 Transfer Pump Blades, After

SN15438595 Transfer Pump Blades (Profile), Before

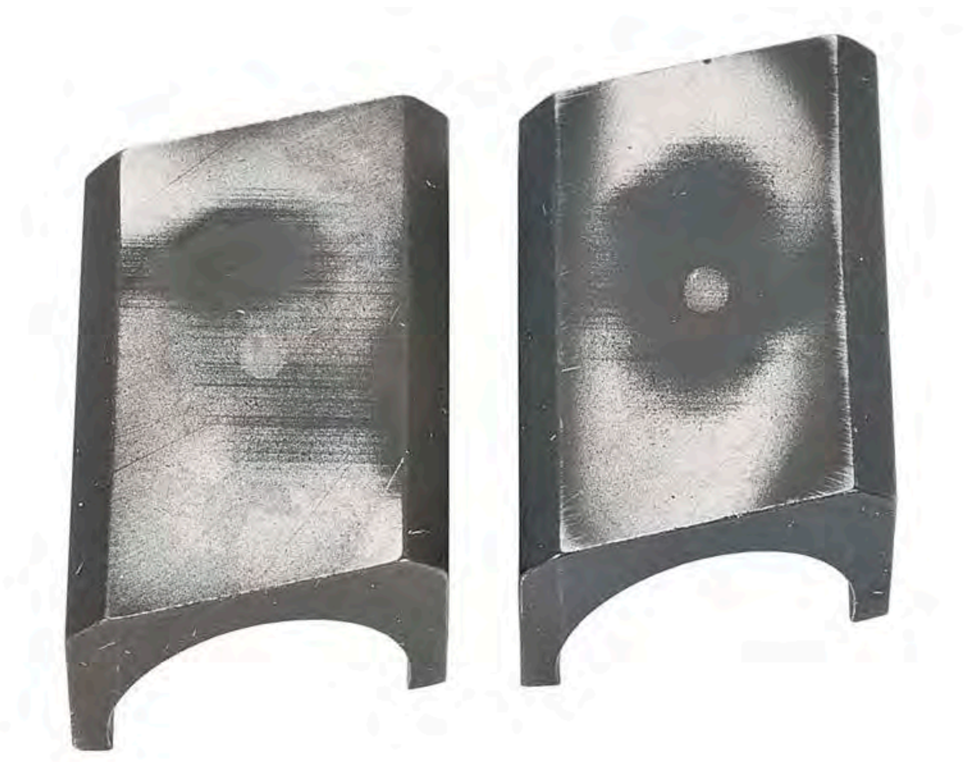
SN15438595 Transfer Pump Blades (Profile), After



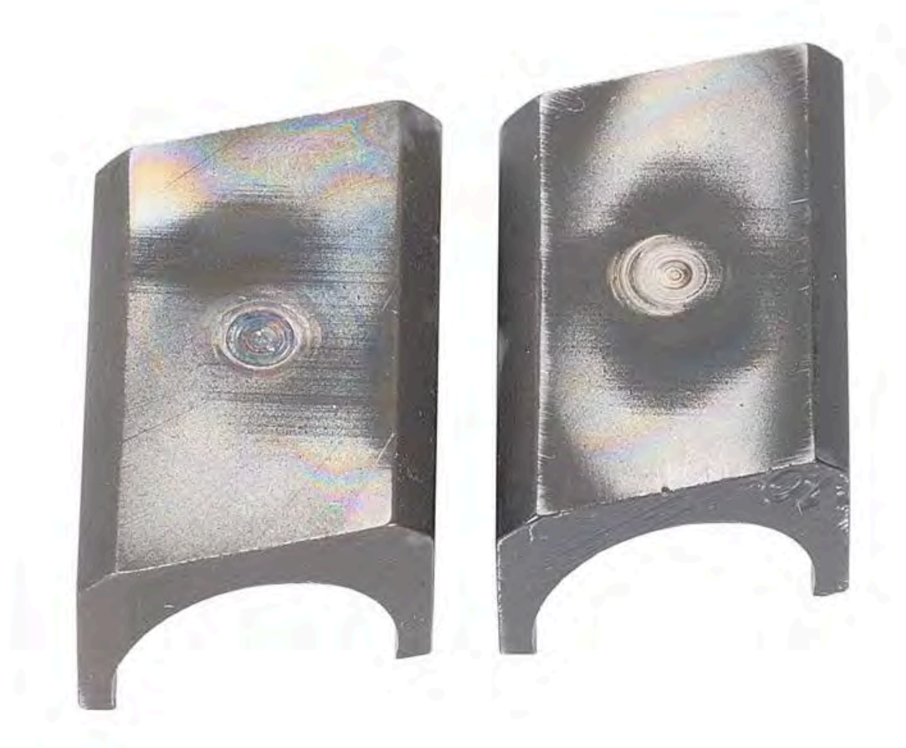
SN15438595 Shoes (Front), Before



SN15438595 Shoes (Front), After



SN15438595 Shoes (Back), Before



SN15438595 Shoes (Back), After

SN15438595 Rollers, Before

SN15438595 Rollers, After

SN15438595 Piston Plungers, Before

SN15438595 Piston Plungers, After

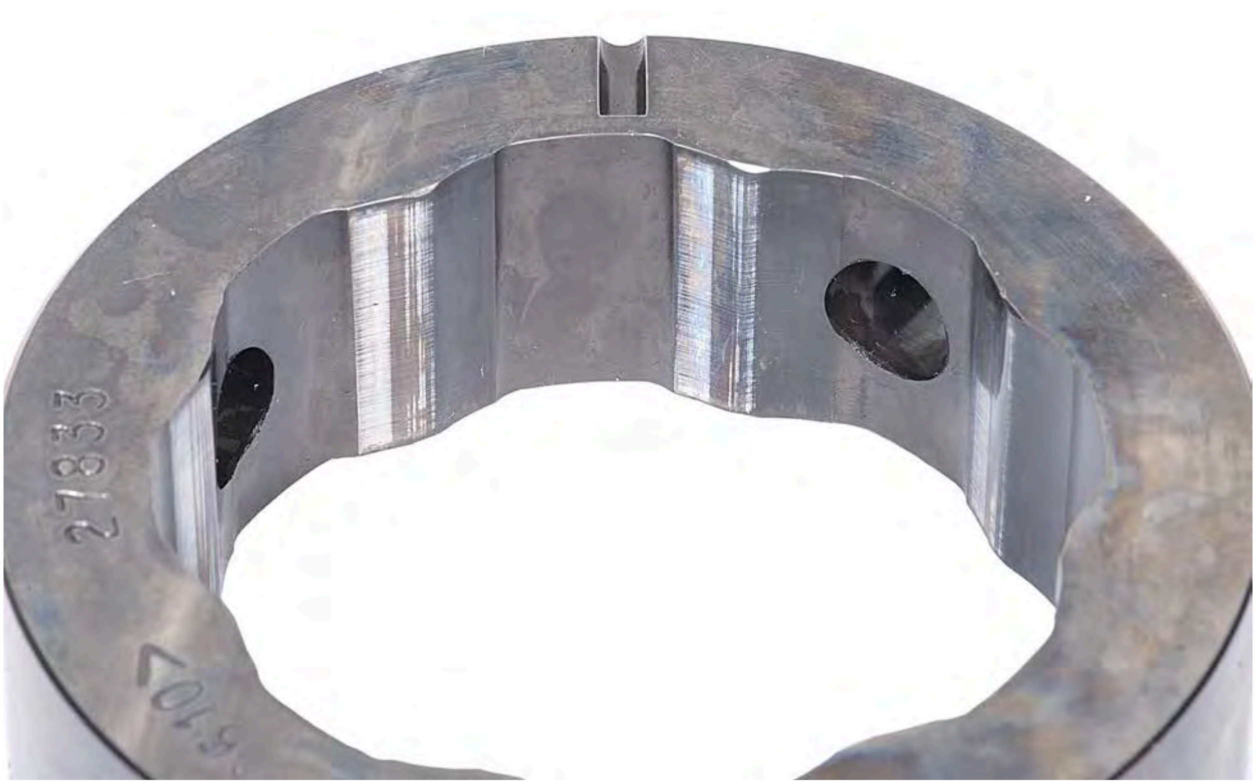
SN15438595 Thrust Washer, Before

SN15438595 Thrust Washer, After

SN15438595 Governor Weight, Before

SN15438595 Governor Weight, After

SN15438595 Cam Ring, Before



SN15438595 Cam Ring, After

SN15438595 Eccentric Ring, Before

SN15438595 Eccentric Ring, After

SN15438595 Rotor (Front), Before

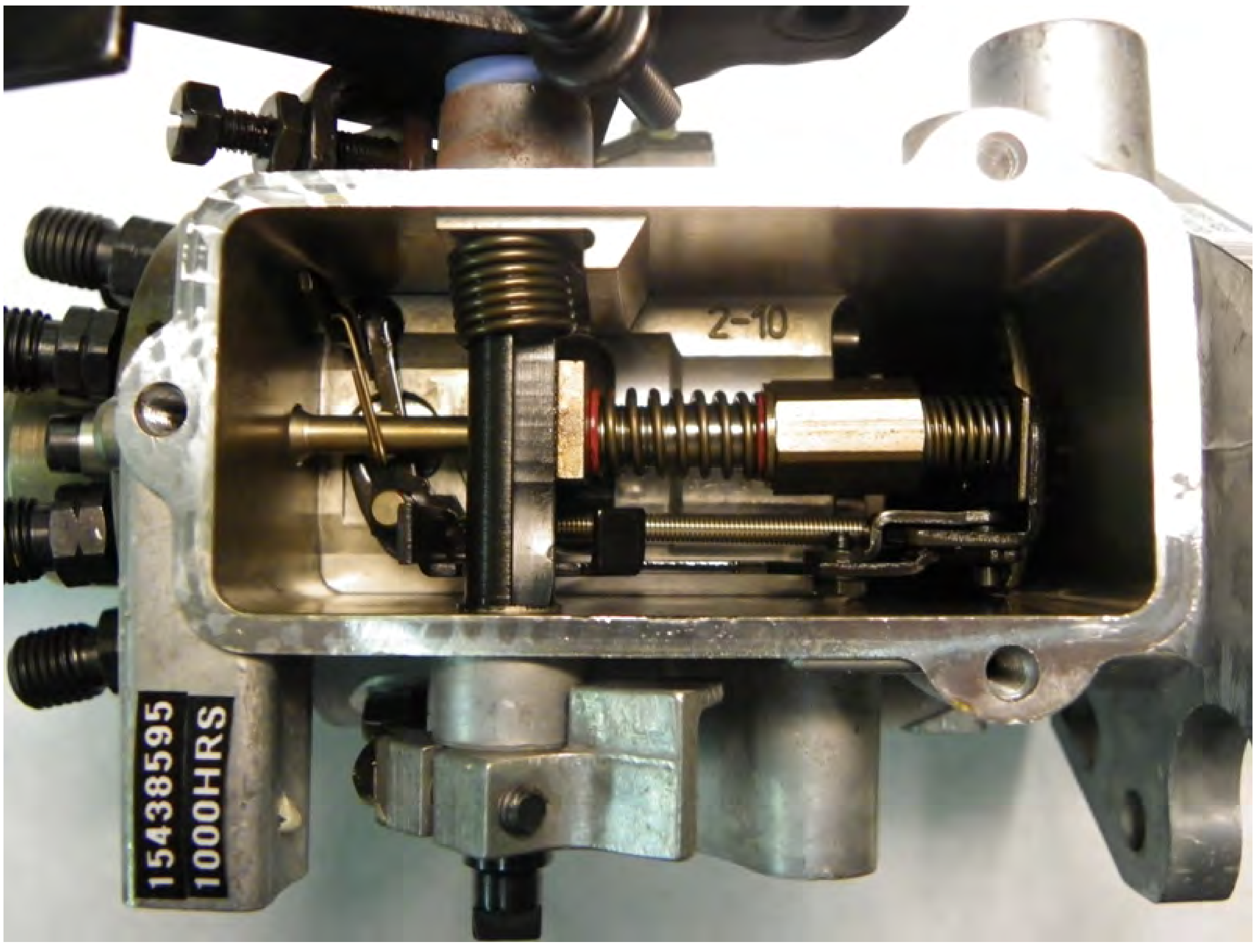
SN15438595 Rotor (Front), After

SN15438595 Rotor (Back), Before

SN15438595 Rotor (Back), After

SN15438595 Drive Tang, Before

SN15438595 Drive Tang, After



SN15438595 Governor Assembly

APPENDIX M

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 50-mg/L INNOSPEC OLI 9070x
Test Number: AF7090-C4T13-57-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 50-mg/L INNOSPEC OLI 9070x

Test Fuel ID: AF7090

Test Temperature: 57°C (135°F)

Test Number: AF7090-C4T13-57-1000

Start of Test Date: September 2, 2011

End of Test Date: November 4, 2011

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure M-1.

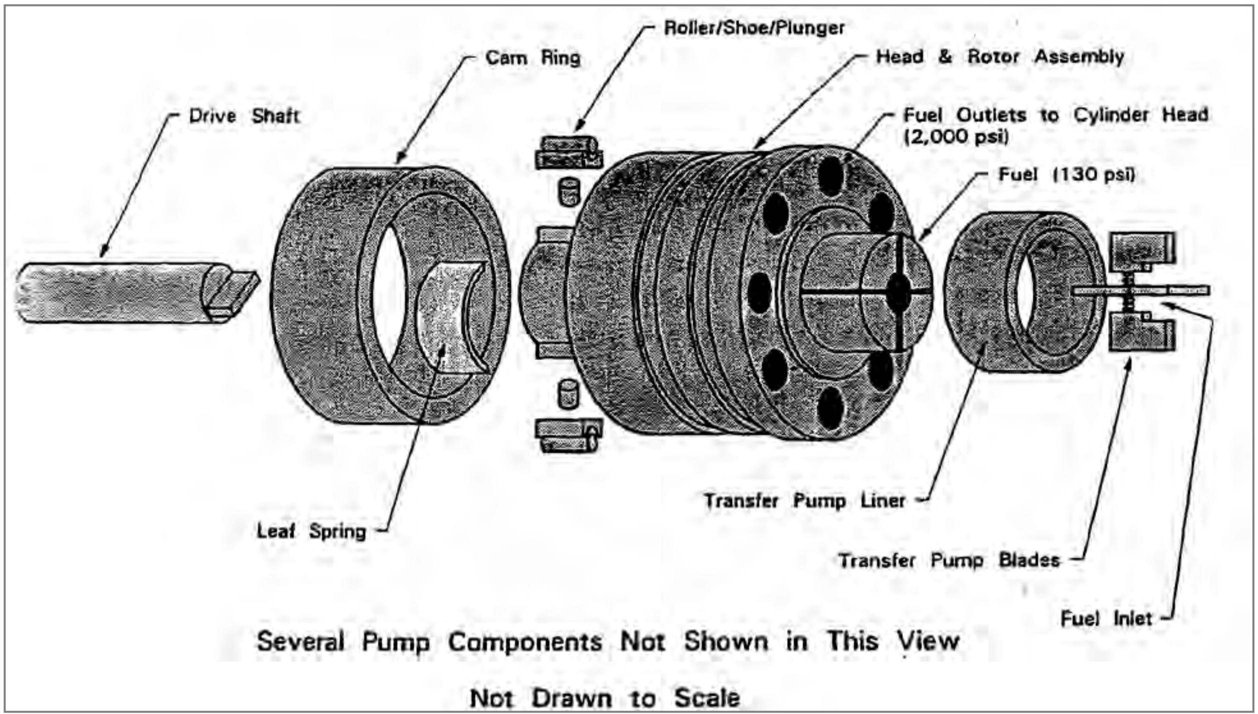


Figure M-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table M-1.

Table M-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	57 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table M-2.

Table M-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1701	2.33
FLO_R	Injected Flow-rate [mL/min]	739.8	20.2
FUELIN_P	Fuel Inlet Pressure [psig]	2.9	0.29
TRNS_P_R	Transfer Pump Pressure [psig]	75.2	0.85
HSG_P_R	Pump Housing Pressure [psig]	12.5	1.17
RTRN_T_R	Fuel Return Temperature [°C]	62.9	1.34
FUEL_T	Fuel Tank Temperature [°C]	30.6	2.5
FUELIN_T	Fuel Inlet Temperature [°C]	57	0.36

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure M-2 through Figure M-4.

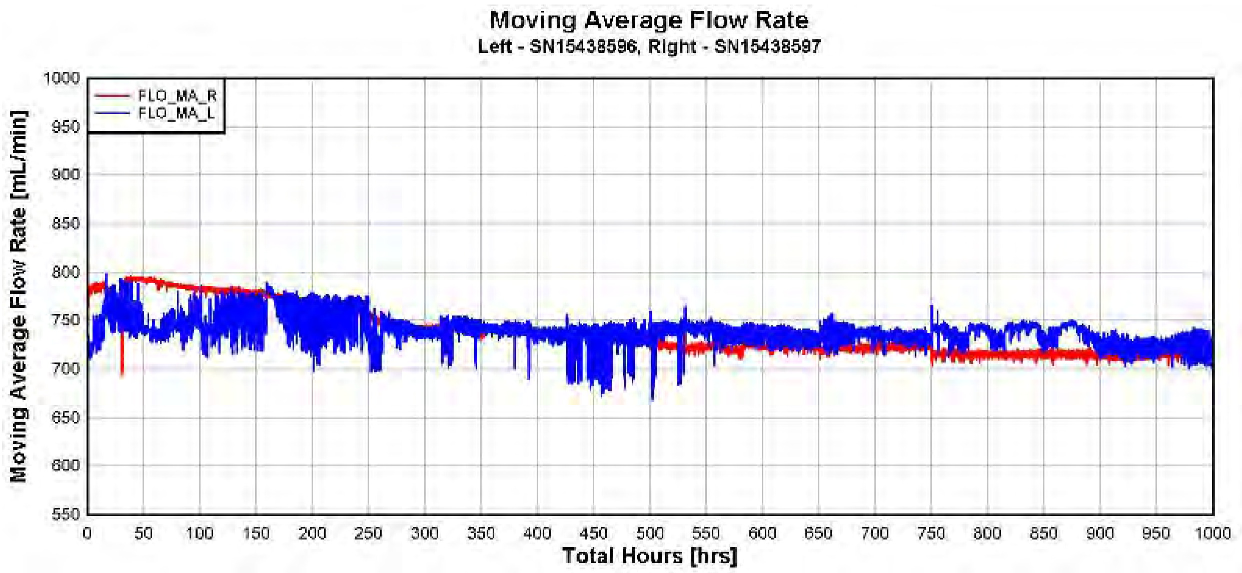


Figure M-2. Pump Flow, Moving Average

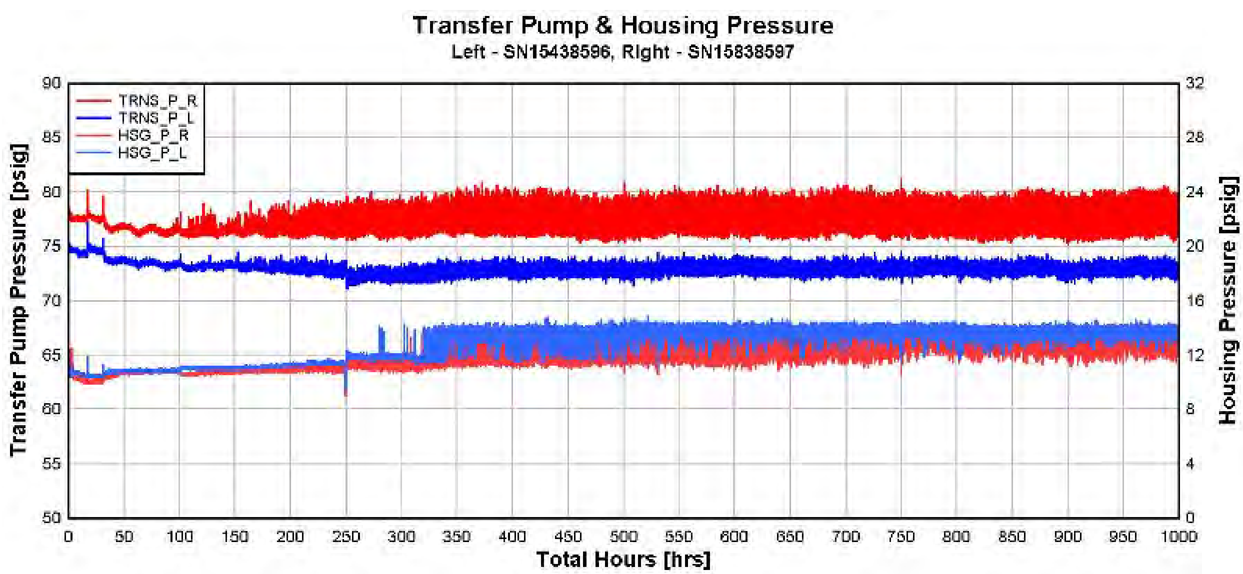


Figure M-3. Transfer Pump & Housing Pressure

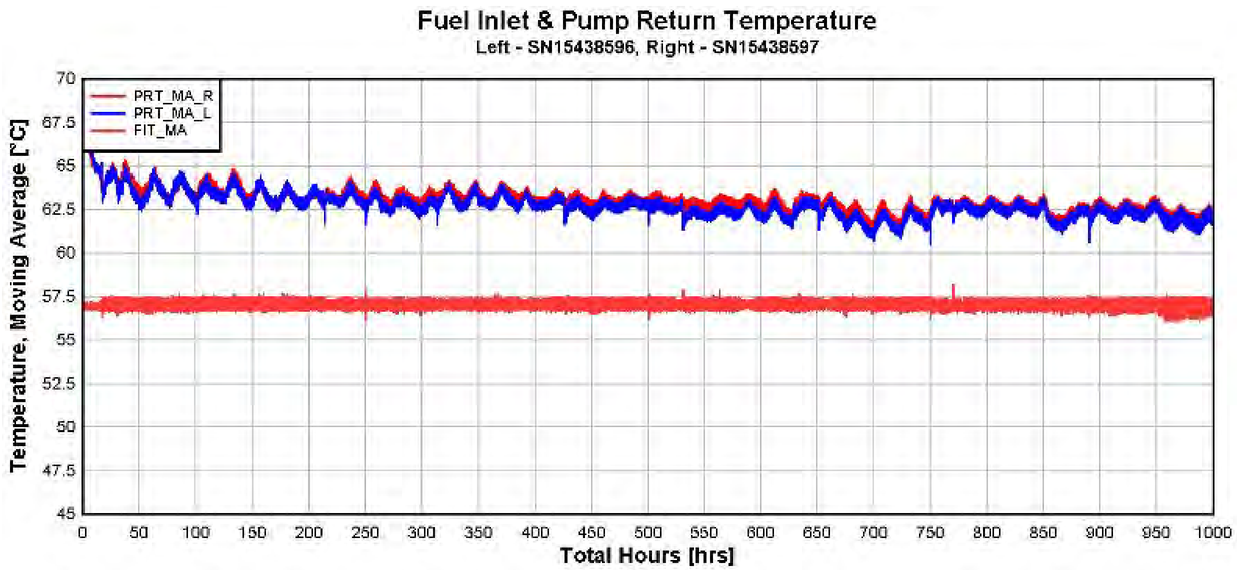


Figure M-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table M-3. (Note – Calibration data to be used as reference only).

Table M-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 13			Test Duration : 1000-hrs.		
Test Fuel :	Jet A-1 w/50-mg/L OLI-9070x @ 135°F			SN : 15436596			SN : 15436597		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	60 psi	2 psi	62 psi	**65 psi**	-3 psi
	Return Fuel	225 cc	375 cc	320 cc	330 cc	-10 cc	340 cc	**415 cc**	-75 cc
350	Low Idle	12 cc	16 cc	16 cc	**10 cc**	6 cc	14 cc	**10 cc**	4 cc
	Housing psi.	8 psi	12 psi	9.0 psi	10.0 psi	-1.0 psi	10.0 psi	10.5 psi	-.5 psi
	Advance	3.50°		**2.75°**	**2.31°**	.44°	4.30°	3.93°	.37°
	Cold Advance Solenoid	.0 psi	1.0 psi	.5 psi	.0 psi	.5 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.5 cc	.0 cc	.5 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	**63.0 cc**	4.0 cc	**66.0 cc**	**63.0 cc**	3.0 cc
1600	WOT Fuel delivery	60 cc		64 cc	**59 cc**	5 cc	61 cc	60 cc	1 cc
	WOT Advance	2.50°	3.50°	2.95°	2.90°	.05°	3.82°	3.48°	.34°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	5.25°	**4.74°**	.51°	6.76°	6.50°	.26°
	Low Idle	11.0°	12.0°	**10.7°**	**10.6°**	.1°	11.0°	11.0°	.0°
1825	Fuel Delivery	33 cc		38 cc	58 cc	-20 cc	38 cc	50 cc	-12 cc
1950	High Idle		15 cc	3 cc	3 cc	cc	2 cc	4 cc	-2 cc
	Transfer pump psi.		125 psi	108 psi	105 psi	3 psi	107 psi	107 psi	0 psi
200	WOT Fuel Delivery	58 cc		60 cc	**55 cc**	5 cc	59 cc	**56 cc**	3 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		52 cc	40 cc	12 cc	48 cc	46 cc	2 cc
	Transfer pump psi.	16 psi		28 psi	26 psi	2 psi	26 psi	25 psi	1 psi
	Housing psi.	.0 psi	12 psi	7.0 psi	9 psi	-2 psi	7 psi	9 psi	-2 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table M-4 and Table M-5.

Table M-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15436596	Test Number: 13	
Fuel Description : Jet A-1 w/50-mg/L OLI-9070x @ 135°F				
	Date:	3/4/2011	1/20/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2538	3.2547	0.0009
Measurement 2	Mass (g)	3.2538	3.2546	0.0008
Measurement 3	Mass (g)	3.2539	3.2547	0.0008
Measurement 4	Mass (g)	3.2540	3.2547	0.0007
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2695	3.2710	0.0015
Measurement 2	Mass (g)	3.2696	3.2708	0.0012
Measurement 3	Mass (g)	3.2697	3.2709	0.0012
Measurement 4	Mass (g)	3.2696	3.2708	0.0012
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2825	3.2833	0.0008
Measurement 2	Mass (g)	3.2827	3.2833	0.0006
Measurement 3	Mass (g)	3.2827	3.2833	0.0006
Measurement 4	Mass (g)	3.2828	3.2833	0.0005
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2985	3.2982	-0.0003
Measurement 2	Mass (g)	3.2984	3.2983	-0.0001
Measurement 3	Mass (g)	3.2984	3.2983	-0.0001
Measurement 4	Mass (g)	3.2984	3.2984	0.0000
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2539	3.2547	0.0008
Transfer Pump Blade 2	Mass (g)	3.2696	3.2709	0.0013
Transfer Pump Blade 3	Mass (g)	3.2827	3.2833	0.0006
Transfer Pump Blade 4	Mass (g)	3.2984	3.2983	-0.0001
	Roller to Roller (in)	1.9760	1.9735	-0.0025
	Eccentricity (in.)	0.0030	0.0040	0.0010
	Drive Backlash (In)	0.0050	ND	

Table M-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15436597	Test Number: 13	
Fuel Description : Jet A-1 w/50-mg/L OLI-9070x @ 135°F				
	Date:	3/4/2011	1/20/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2774	3.2835	0.0061
Measurement 2		3.2776	3.2836	0.0060
Measurement 3		3.2775	3.2837	0.0062
Measurement 4		3.2774	3.2837	0.0063
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2175	3.2241	0.0066
Measurement 2		3.2175	3.2241	0.0066
Measurement 3		3.2176	3.2240	0.0064
Measurement 4		3.2175	3.2240	0.0065
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2868	3.2918	0.0050
Measurement 2		3.2867	3.2918	0.0051
Measurement 3		3.2867	3.2918	0.0051
Measurement 4		3.2868	3.2919	0.0051
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2039	3.2124	0.0085
Measurement 2		3.2038	3.2126	0.0088
Measurement 3		3.2038	3.2124	0.0086
Measurement 4		3.2038	3.2124	0.0086
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2775	3.2836	0.0061
Transfer Pump Blade 2		3.2175	3.2241	0.0065
Transfer Pump Blade 3		3.2868	3.2918	0.0051
Transfer Pump Blade 4		3.2038	3.2125	0.0086
	Roller to Roller (in)	1.9760	1.9742	-0.0018
	Eccentricity (in.)	0.0070	0.0090	0.0020
	Drive Backlash (In)	ND	0.0070	

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table M-6.

Table M-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection												
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
13	15436596	Jet A-1 w/50-mg/L OLI-9070x @ 135°F	13-1	2050	1825	Pass	Pass	Pass	Pass	Pass	Pass
			13-2	2175	1925	Pass	Pass	Pass	Pass	Pass	Pass
			13-3	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			13-4	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			13-5	2175	1850	Pass	Pass	Pass	Pass	Pass	Pass
			13-6	2100	1825	Pass	Pass	Pass	Pass	Pass	Pass
			13-7	2125	1900	Pass	Pass	Pass	Pass	Pass	Pass
			13-8	2100	1825	Pass	Pass	Pass	Pass	Pass	Pass
13	15436597	Jet A-1 w/50-mg/L OLI-9070x @ 135°F	13-11	2100	1800	Pass	Pass	Pass	Pass	Pass	Pass
			13-12	2125	1900	Pass	Pass	Pass	Pass	Pass	Pass
			13-13	2075	1775	Pass	Pass	Pass	Pass	Pass	Pass
			13-14	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			13-15	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			13-16	2125	1750	Pass	Pass	Pass	Pass	Pass	Pass
			13-17	2125	1775	Pass	Pass	Pass	Pass	Pass	Pass
			13-18	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table M-7 and Table M-8.

Table M-7. Stanadyne Left Pump Parts Evaluation

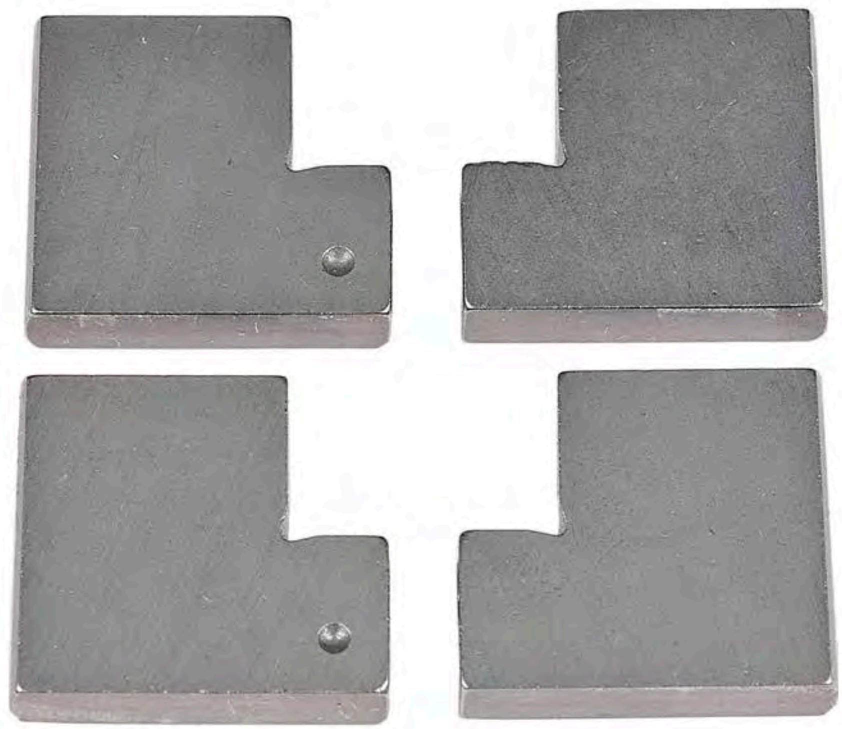
Pump Type : DB2831-5079		SN: 15436596
Test Condition : Jet A-1 w/50-mg/L OLI-9070x @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at roller slots and liner contact	2
BLADE SPRINGS	Rubbing wear	1
LINER	Wear on 40% of liner	2
TRANSFER PUMP REGULATOR	Wear mark from rotor	1.5
REGULATOR PISTON	Polishing wear on two spots	1.5
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	3
DELIVERY VALVE	Polishing wear	2.5
PLUNGERS	Polishing wear	2
SHOES	Dimple on back, wear from leaf spring	2
ROLLERS	Both have wear scars and discoloration	3.5
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Wear marks from rollers.	1.5
THRUST WASHER	Wear from weights. Slight groove	2
THRUST SLEEVE	Light wearfrom governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact thrust washer	2
LINK HOOK	Normal	0
METERING VAVLE	Light polishing wear	1
DRIVE SHAFT TANG	Light polishing wear	11
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal in spec	1
ADVANCE PISTON	Scuffing wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	2.130

Table M-8. Stanadyne Right Pump Parts Evaluation

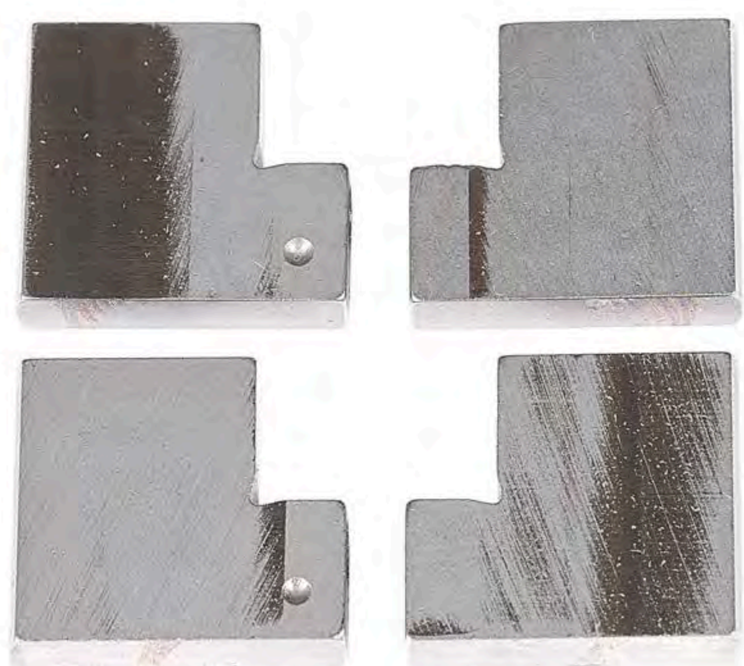
Pump Type : DB2831-5079	SN: 15436597
Test Condition : Jet A-1 w/50-mg/L OLI-9070x @ 135°F	Pump Duration : 1000.-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Wear at roller slots and liner contact	2
BLADE SPRINGS	Rubbing wear	1
LINER	Wear on 60% of liner	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor	1.5
REGULATOR PISTON	Polishing wear on two spots	1.5
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	wear from rotor contact	3
DELIVERY VALVE	Polishing wear	2.5
PLUNGERS	Polishing wear	2
SHOES	Dimple on back, wear from leaf spring	2
ROLLERS	Light pitting and discoloration	1.5
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Wear marks from rollers.	1
THRUST WASHER	Polishing wear from weights	1.5
THRUST SLEEVE	Light wearfrom governor arm fingers	1
GOVORNER WEIGHTS	Wear at foot of weight contact thrust washer	1.5
LINK HOOK	Normal	1
METERING VAVLE	Light polishing wear	1
DRIVE SHAFT TANG	Light polishing wear	1.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal in spec	1
ADVANCE PISTON	Scuffing wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.630

PHOTOGRAPHS FOR LEFT PUMP



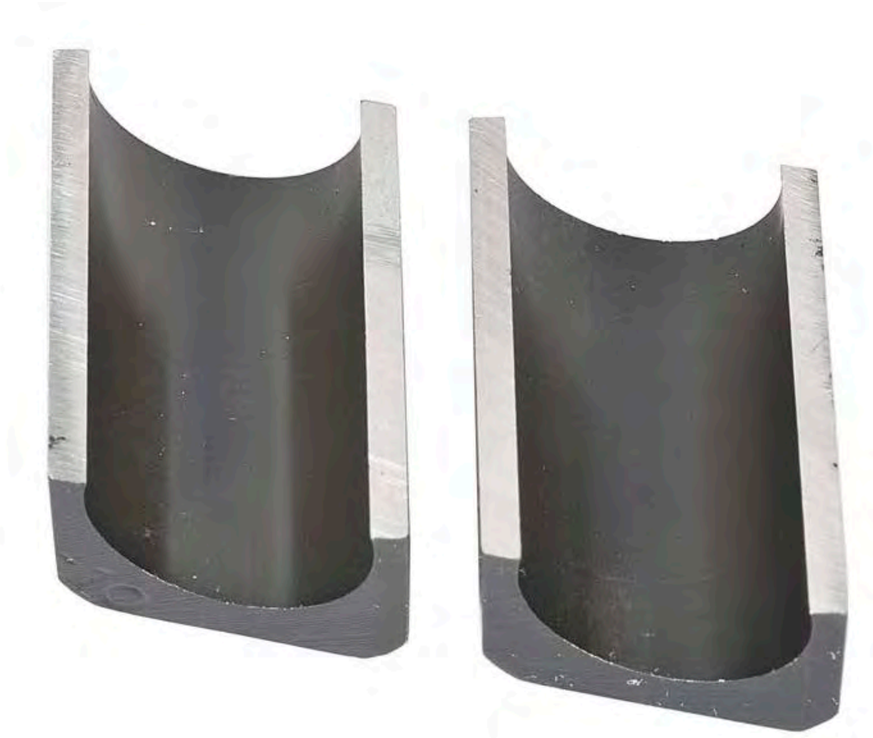
SN15438596 Transfer Pump Blades (Side), Before



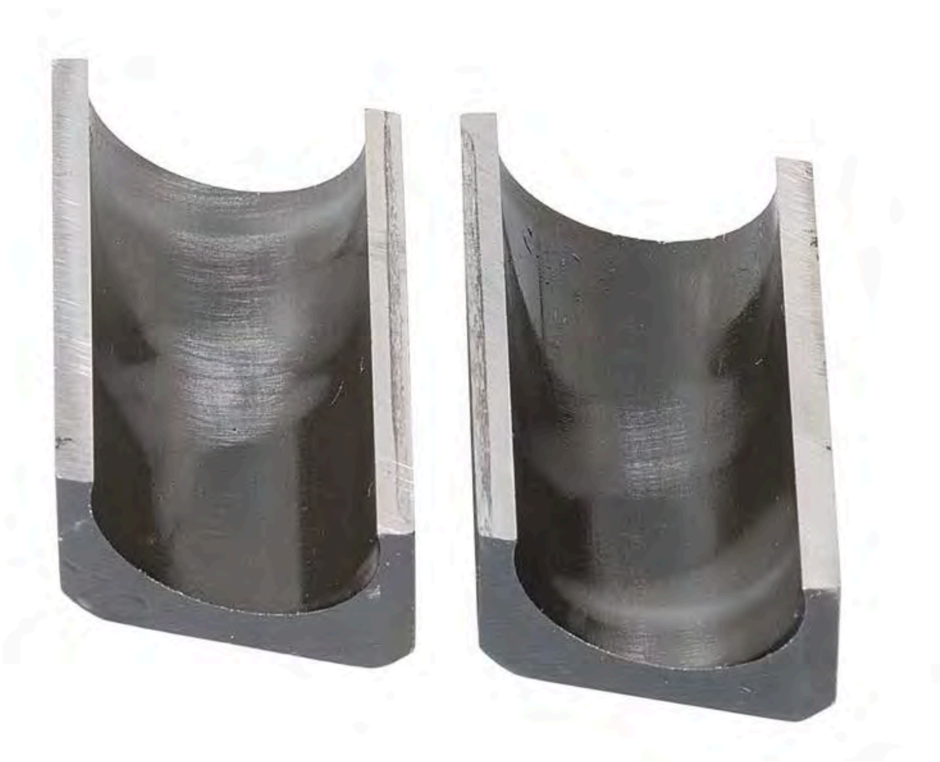
SN15438596 Transfer Pump Blades (Side), After

SN15438596 Transfer Pump Blades (Profile), Before

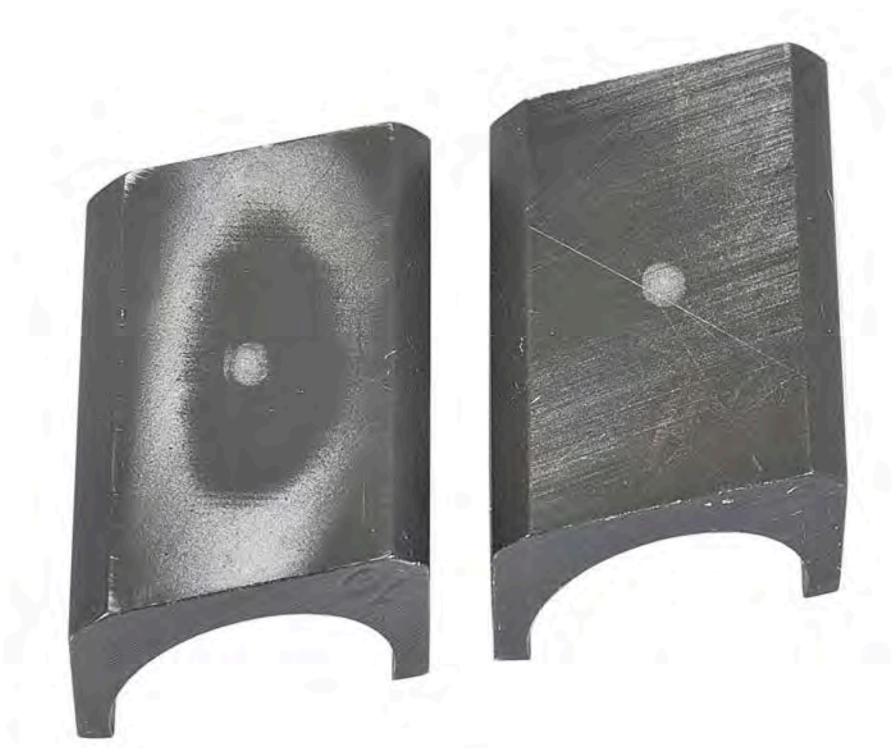
SN15438596 Transfer Pump Blades (Profile), After



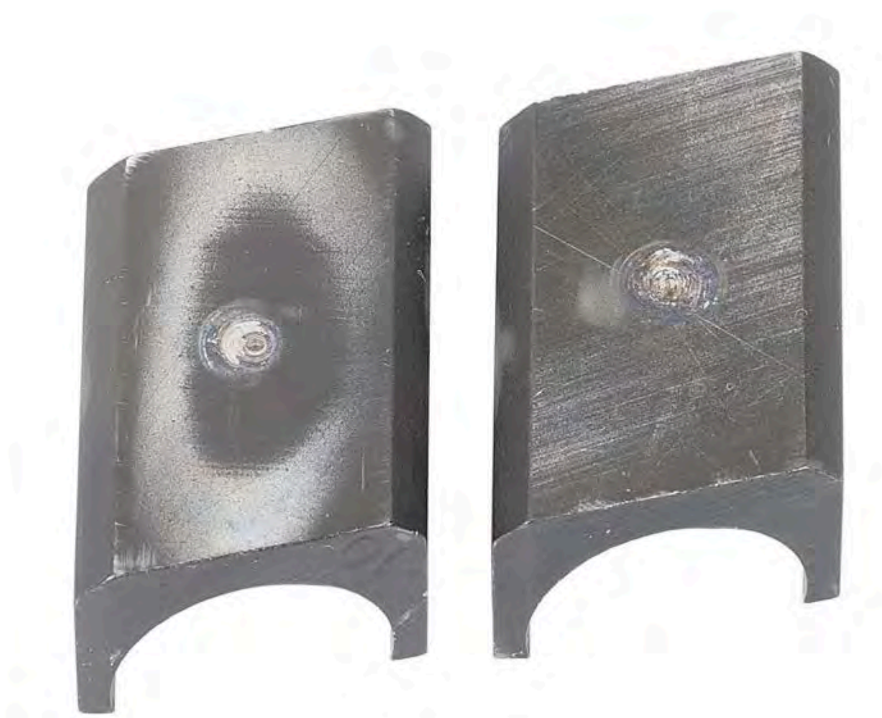
SN15438596 Shoes (Front), Before



SN15438596 Shoes (Front), After



SN15438596 Shoes (Back), Before



SN15438596 Shoes (Back), After

SN15438596 Rollers, Before

SN15438596 Rollers, After

SN15438596 Piston Plungers, Before

SN15438596 Piston Plungers, After

SN15438596 Thrust Washer, Before

SN15438596 Thrust Washer, After

SN15438596 Governor Weight, Before

SN15438596 Governor Weight, After

SN15438596 Cam Ring, Before

SN15438596 Cam Ring, After

SN15438596 Eccentric Ring, Before

SN15438596 Eccentric Ring, After

SN15438596 Rotor (Front), Before

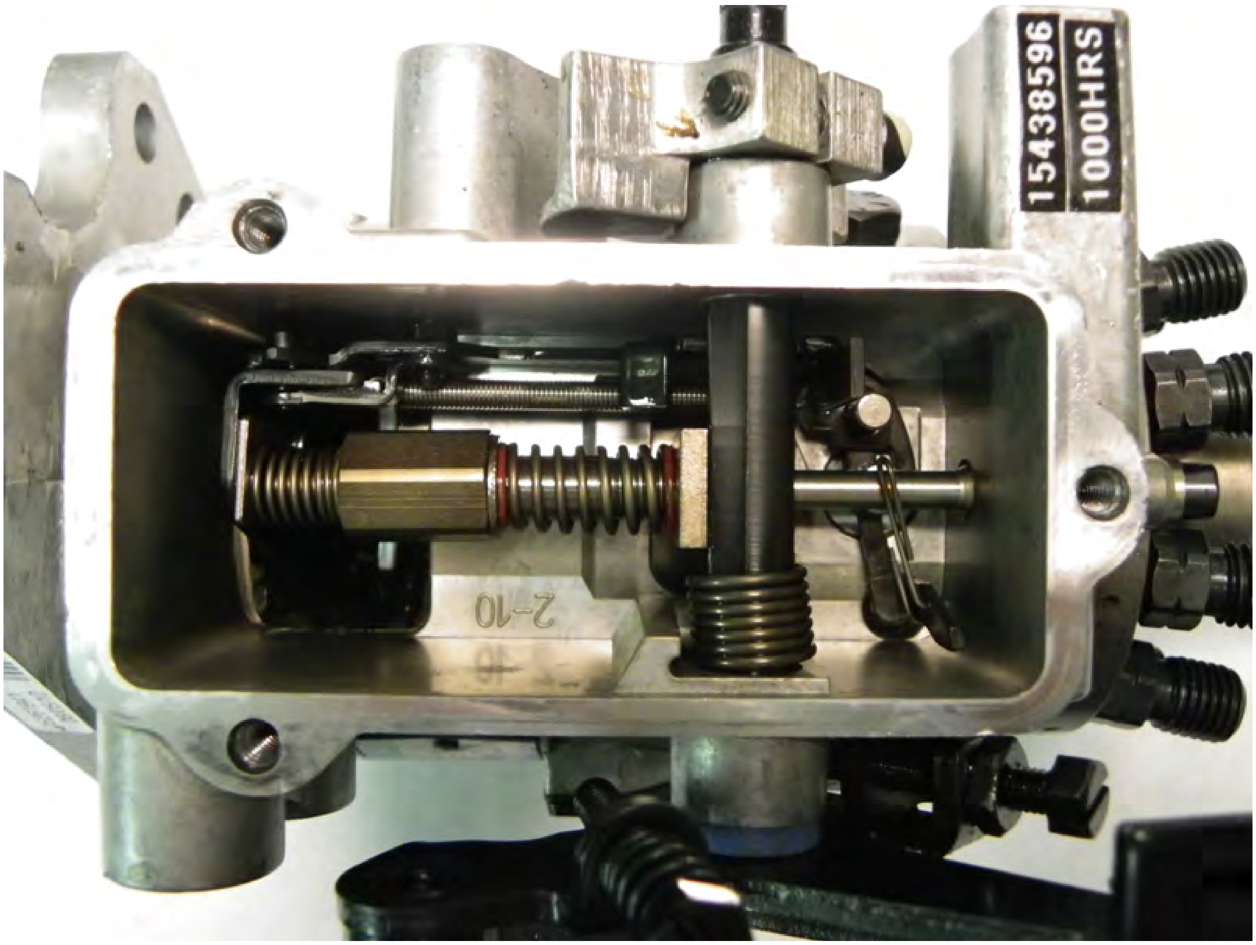
SN15438596 Rotor (Front), After

SN15438596 Rotor (Back), Before

SN15438596 Rotor (Back), After

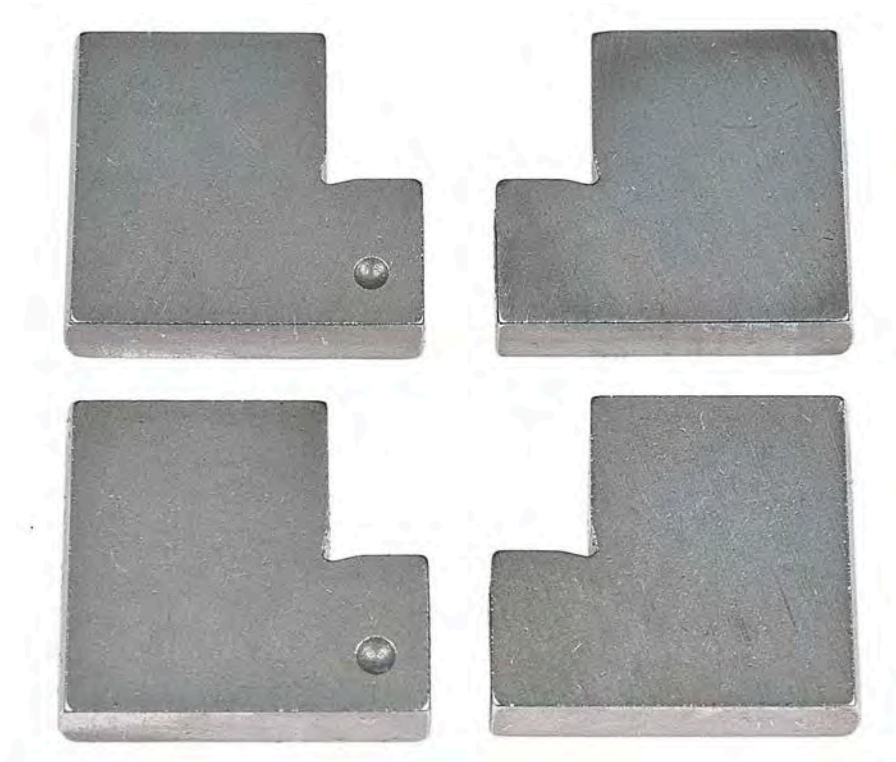
SN15438596 Drive Tang, Before

SN15438596 Drive Tang, After

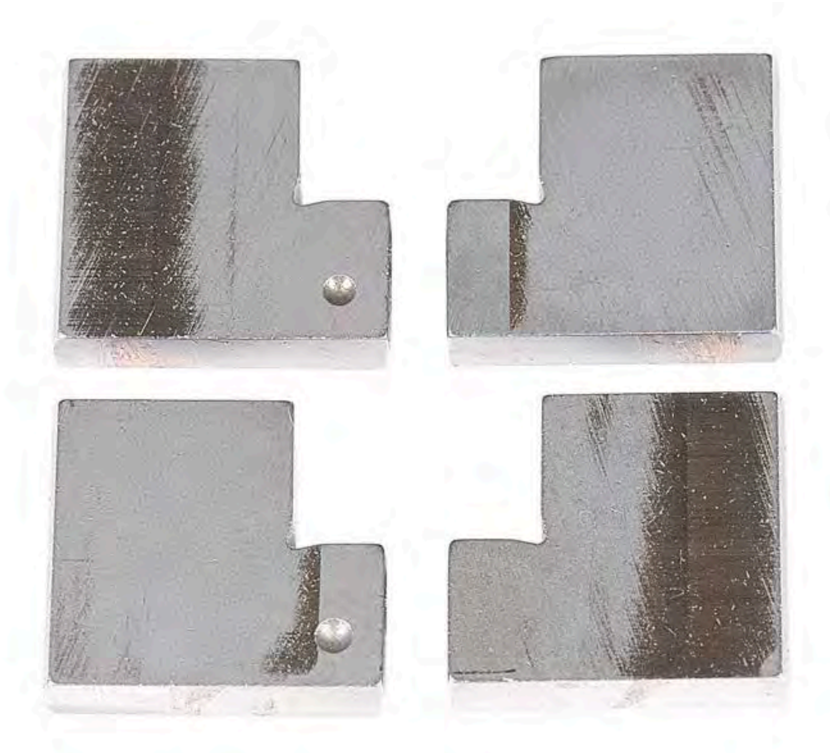


SN15438596 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



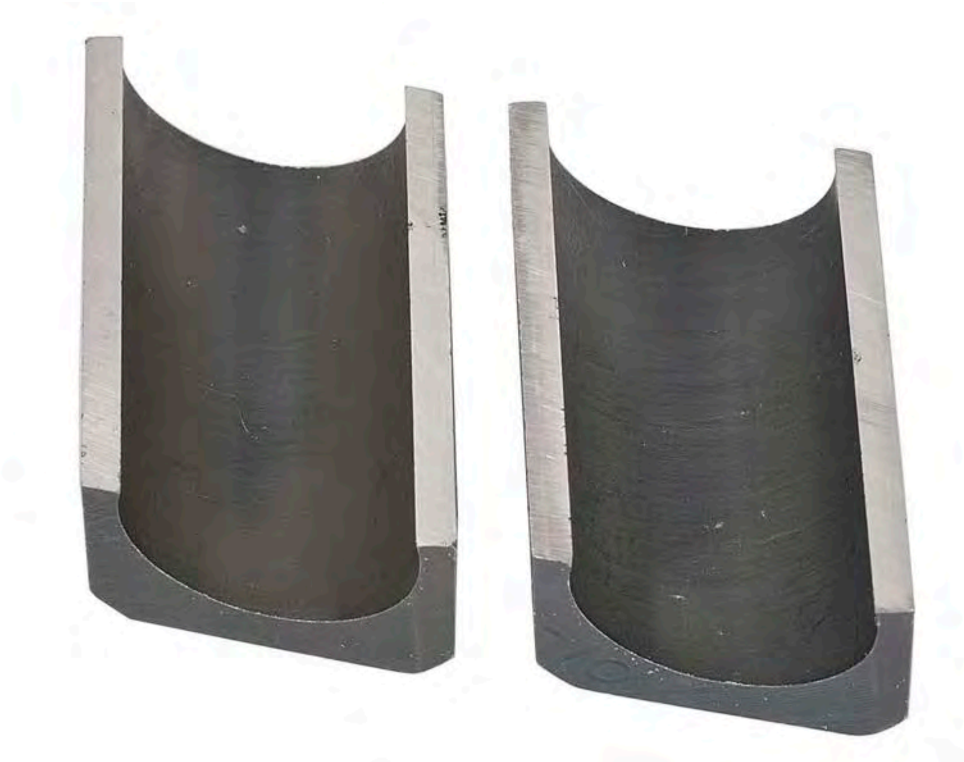
SN15438597 Transfer Pump Blades, Before



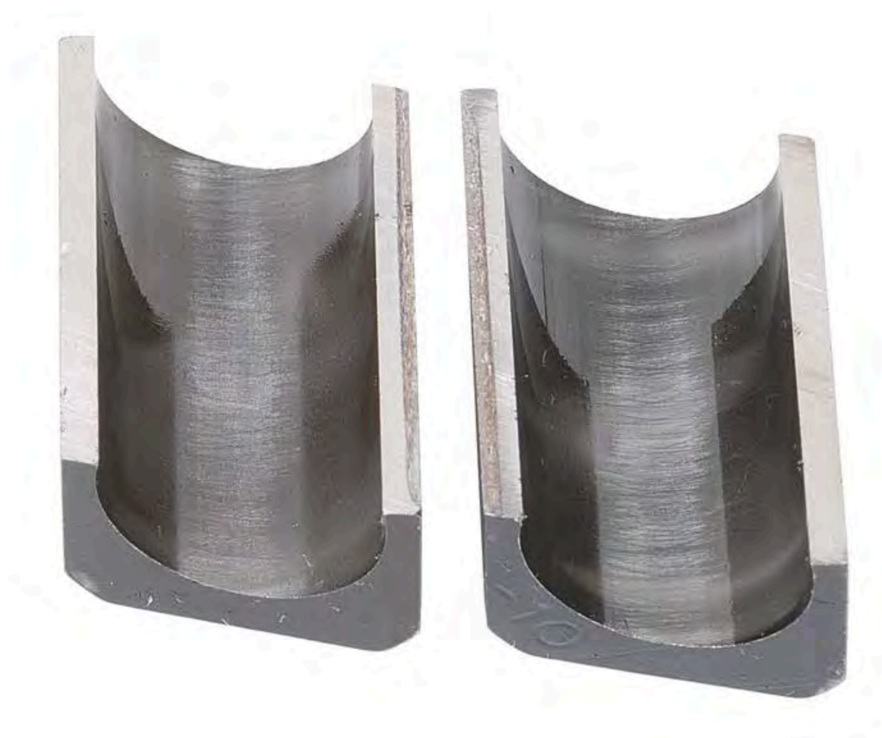
SN15438597 Transfer Pump Blades, After

SN15438597 Transfer Pump Blades (Profile), Before

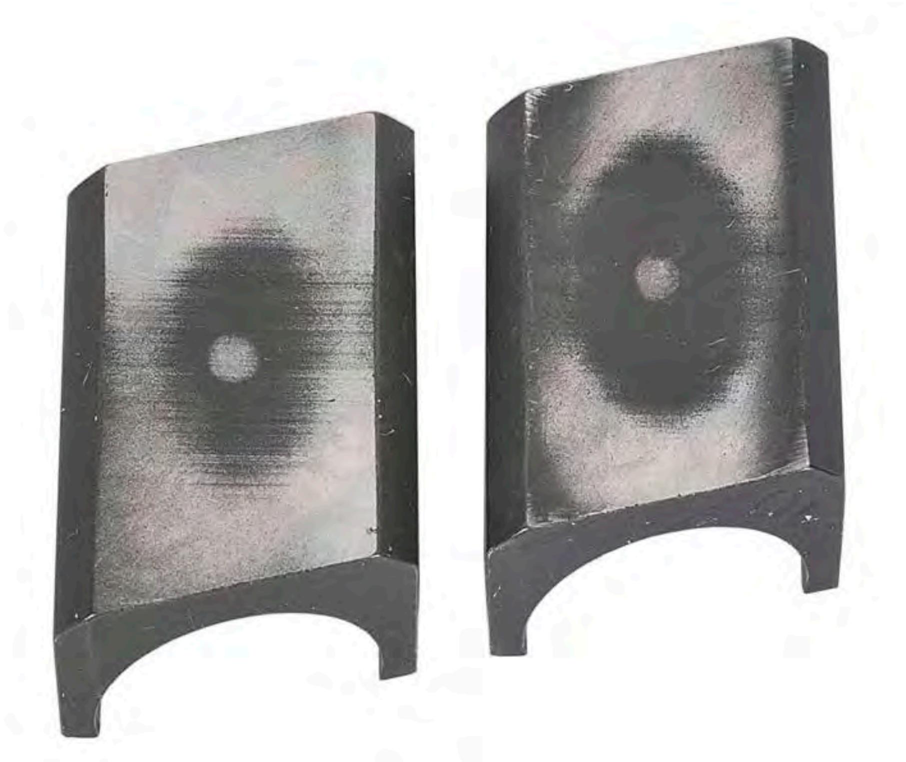
SN15438597 Transfer Pump Blades (Profile), After



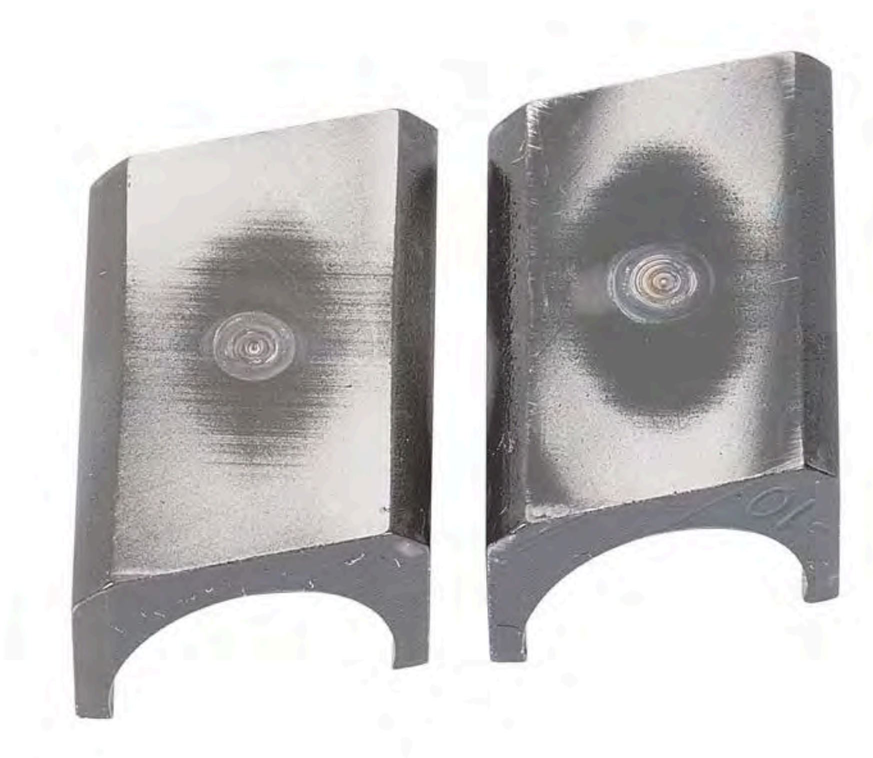
SN15438597 Shoes (Front), Before



SN15438597 Shoes (Front), After



SN15438597 Shoes (Back), Before



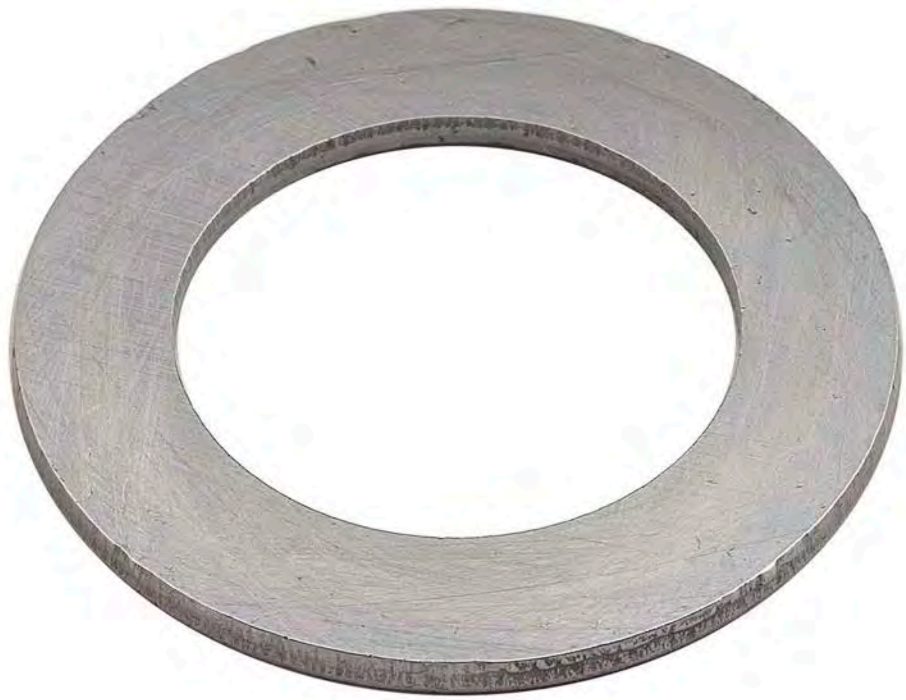
SN15438597 Shoes (Back), After

SN15438597 Rollers, Before

SN15438597 Rollers, After

SN15438597 Piston Plungers, Before

SN15438597 Piston Plungers, After

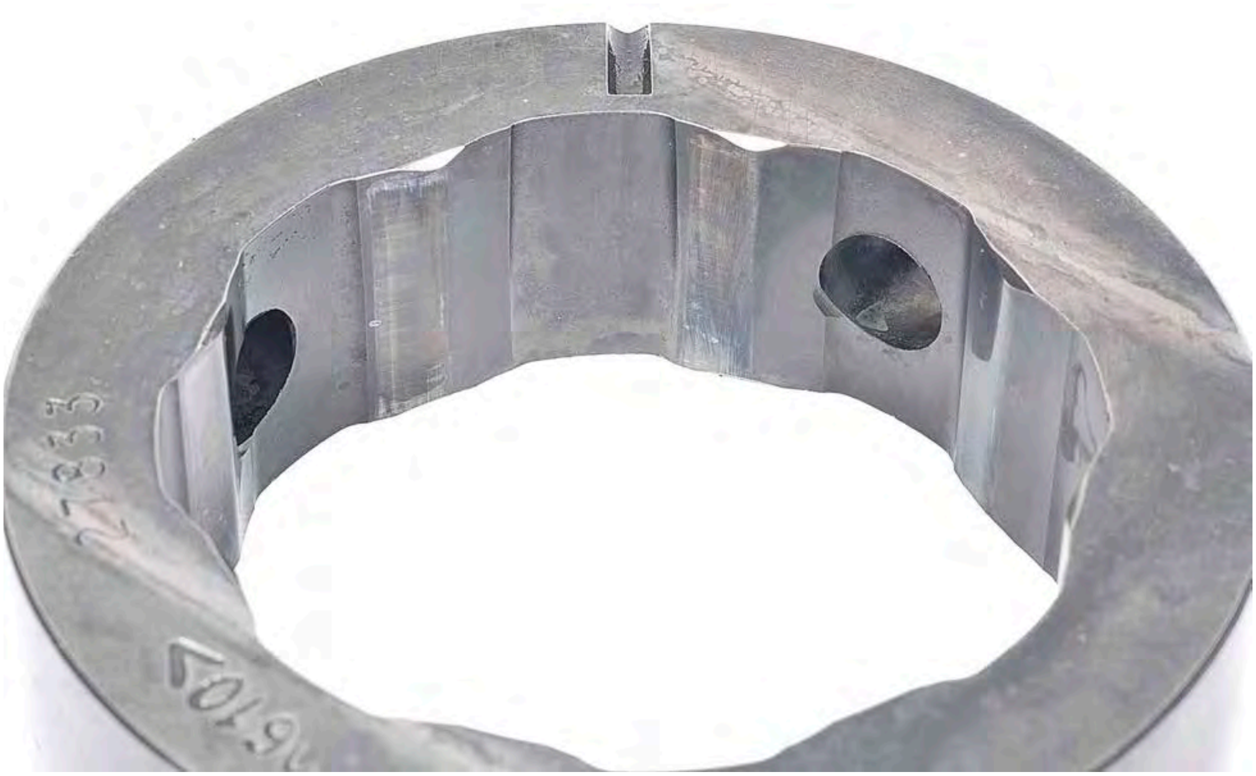


SN15438597 Thrust Washer, Before

SN15438597 Thrust Washer, After

SN15438597 Governor Weight, Before

SN15438597 Governor Weight, After



SN15438597 Cam Ring, Before

SN15438597 Cam Ring, After

SN15438597 Eccentric Ring, Before

SN15438597 Eccentric Ring, After

SN15438597 Rotor (Front), Before

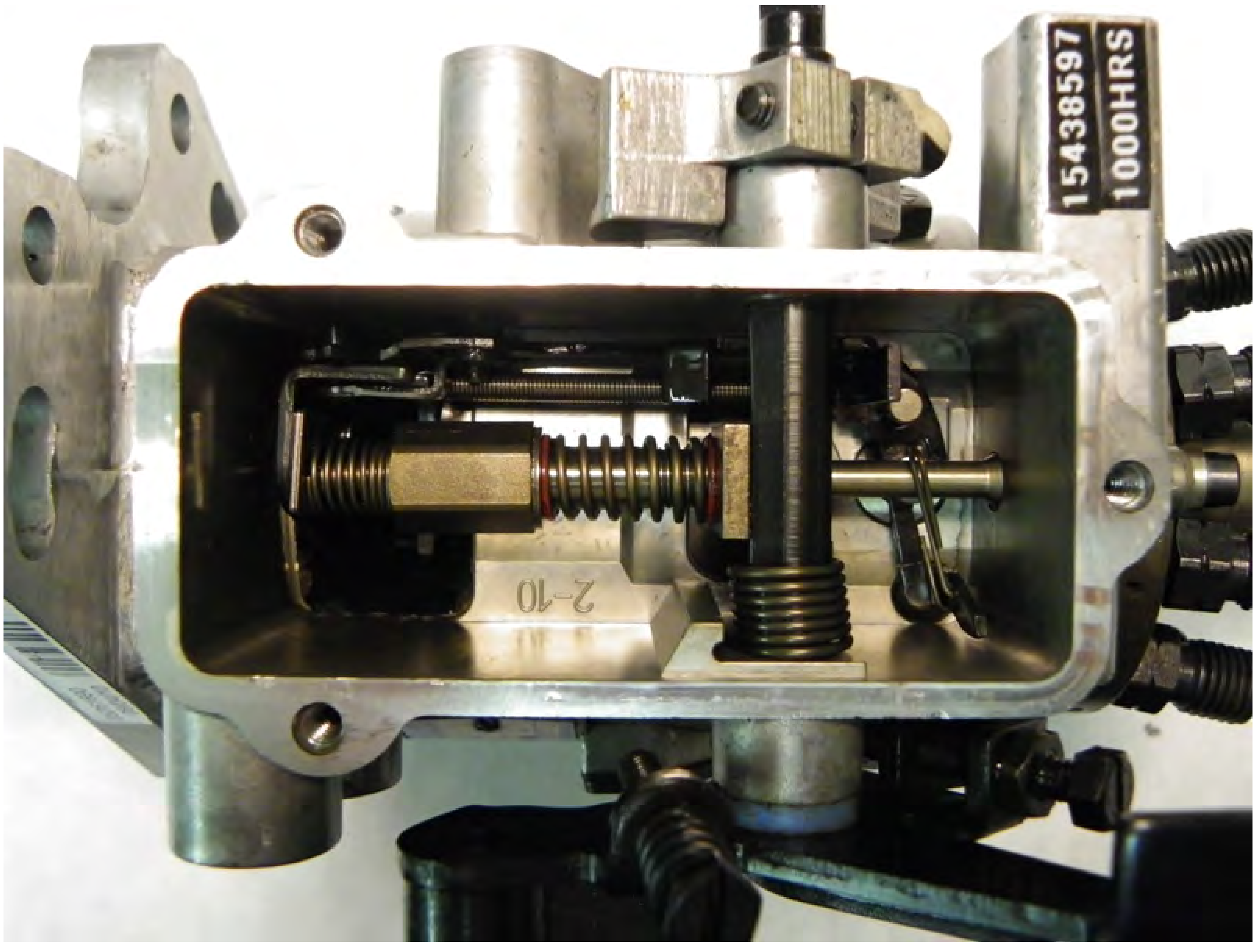
SN15438597 Rotor (Front), After

SN15438597 Rotor (Back), Before

SN15438597 Rotor (Back), After

SN15438597 Drive Tang, Before

SN15438597 Drive Tang, After



SN15438597 Governor Assembly

APPENDIX N

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: Jet A-1 with 50-mg/L Innospec OLI-9070x
Test Number: C3T14-77-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: Jet A-1 with 50-mg/L Innospec OLI-9070x
Test Fuel ID: AF7090
Test Temperature: 77°C (170°F)
Test Number: C3T14-77-1000
Start of Test Date: October 27, 2011
End of Test Date: January 9, 2012
Test Duration: 750/1,000 Hrs

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure N-1.

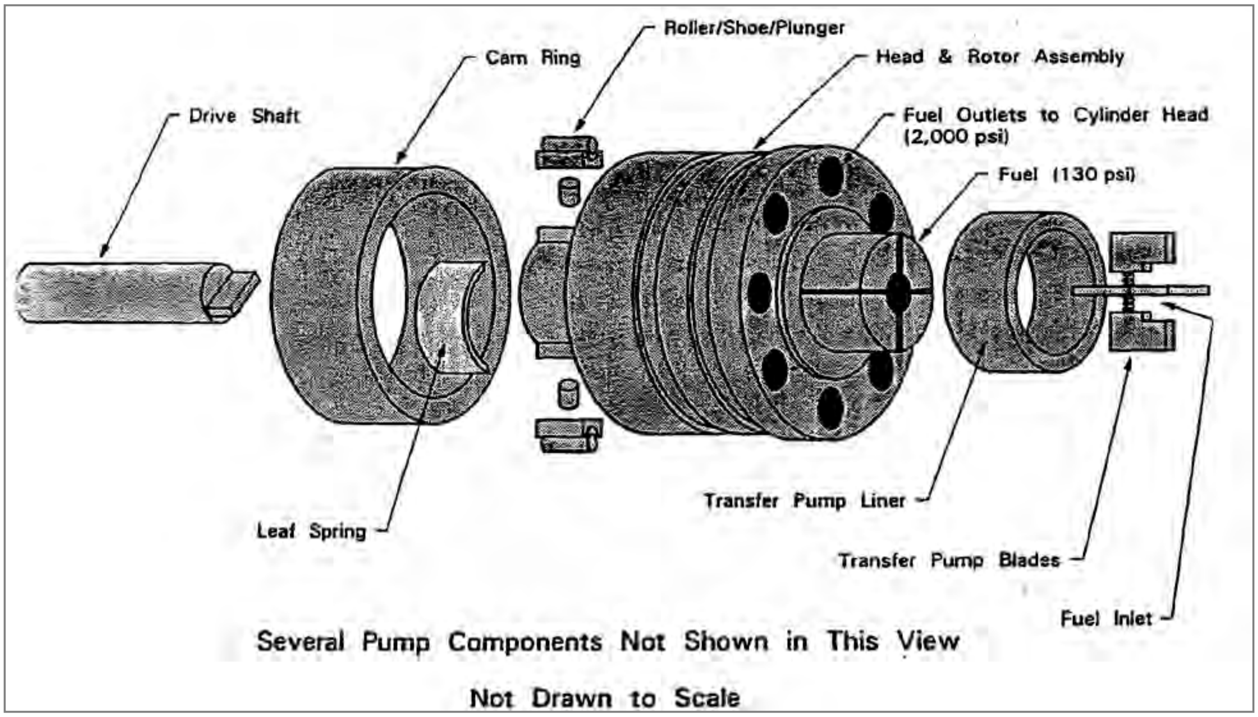


Figure N-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table N-1.

Table N-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	77 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table N-2.

Table N-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1696	7.83
FLO_R	Injected Flow-rate [mL/min]	733.85	15
FUELIN_P	Fuel Inlet Pressure [psig]	2.8	0.44
TRNS_P_R	Transfer Pump Pressure [psig]	67.92	0.56
HSG_P_R	Pump Housing Pressure [psig]	12.02	0.74
RTRN_T_R	Fuel Return Temperature [°C]	82.97	1.13
FUEL_T	Fuel Tank Temperature [°C]	28.4	4.8
FUELIN_T	Fuel Inlet Temperature [°C]	77	0.95

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure N-2 through Figure N-4.

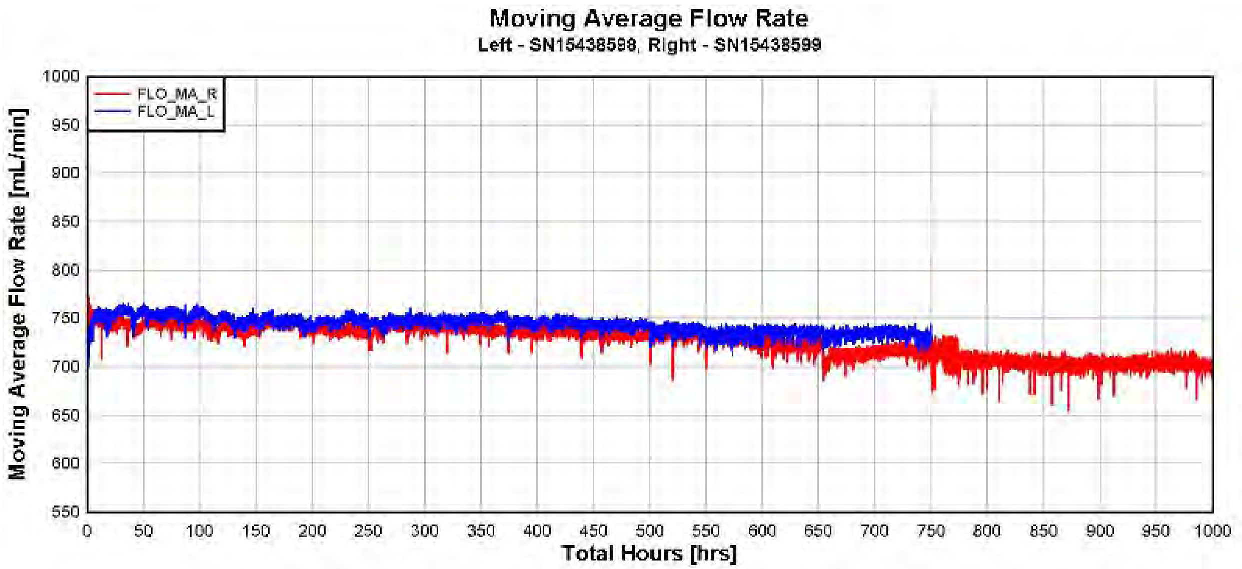


Figure N-2. Pump Flow, Moving Average

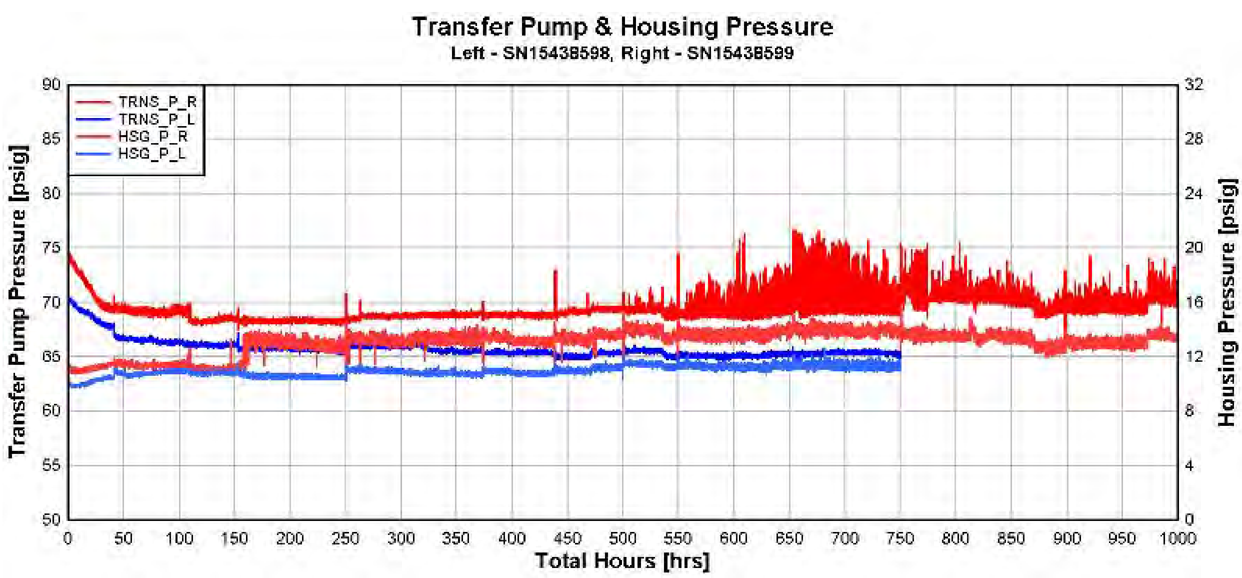


Figure N-3. Transfer Pump & Housing Pressure

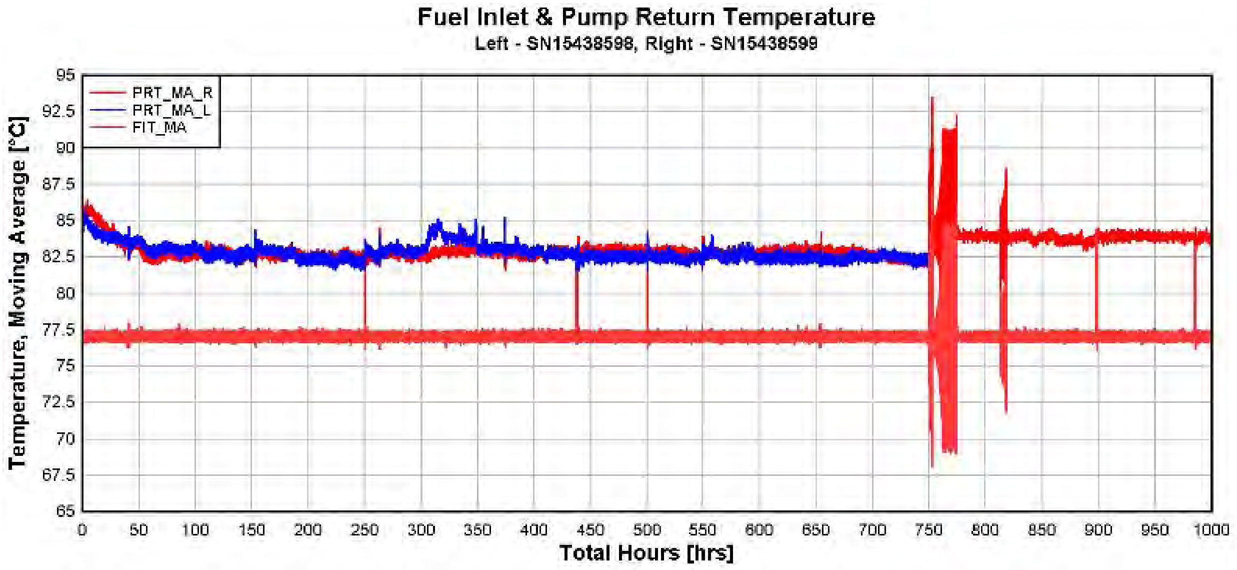


Figure N-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table N-3. (Note – Calibration data to be used as reference only).

Table N-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 14			Test Duration : 1000-hrs.		
Test Fuel : Jet A-1 w/50-mg/L OLI-9070x @ 170°F				SN : 15438598			SN : 15438599		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 750.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	ND		62 psi	61 psi	1 psi
	Return Fuel	225 cc	375 cc	328 cc	ND		270 cc	365 cc	-95 cc
350	Low Idle	12 cc	16 cc	14 cc	ND		14 cc	**2 cc**	12 cc
	Housing psi.	8 psi	12 psi	8.0 psi	ND		10.0 psi	9.5 psi	.5 psi
	Advance	3.50°		4.89°	ND		4.79°	4.63°	.16°
	Cold Advance Solenoid	.0 psi	1.0 psi	.5 psi	ND		.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	ND		.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	ND		68.0 cc	**65.0 cc**	3.0 cc
1600	WOT Fuel delivery	60 cc		64 cc	ND		63 cc	60 cc	3 cc
	WOT Advance	2.50°	3.50°	3.42°	ND		3.05°	**5.21°**	-2.16°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	ND		22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	7.01°	ND		6.19°	6.34°	-.15°
	Low Idle	11.0°	12.0°	**10.9°**	ND		**11.0°**	11.1°	-.1°
1825	Fuel Delivery	33 cc		38 cc	ND		37 cc	48 cc	-11 cc
1950	High Idle		15 cc	2 cc	ND		2 cc	2 cc	cc
	Transfer pump psi.		125 psi	106 psi	ND		109 psi	105 psi	4 psi
200	WOT Fuel Delivery	58 cc		62 cc	ND		62 cc	60 cc	2 cc
	WOT Shut-Off		4 cc	0 cc	ND		0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		52 cc	ND		52 cc	48 cc	4 cc
	Transfer pump psi.	16 psi		22 psi	ND		30 psi	25 psi	5 psi
	Housing psi.	.0 psi	12 psi	6.0 psi	ND		7 psi	7 psi	0 psi
	Air Timing	-1.00°	.00°	-.50°	ND		-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes : Pump SN:15438598 - Severe wear in needle bearings caused disintegration of fluorosilicone and viton shaft seals, when test stand was restarted at 750 hrs after fuel drum changed fuel spewed out of pump into gearbox. Pump could not be calibrated.

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table N-4 and Table N-5.

Table N-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438598	Test Number: 14	
Fuel Description : Jet A-1 w/50-mg/L OLI-9070x @ 170°F				
	Date:	3/14/2011	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***750-hrs.***	***Change***
Measurement 1	Mass (g)	3.2398	3.2235	-0.0163
Measurement 2		3.2399	3.2235	-0.0164
Measurement 3		3.2399	3.2234	-0.0165
Measurement 4		3.2400	3.2235	-0.0165
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2752	3.2549	-0.0203
Measurement 2		3.2752	3.2549	-0.0203
Measurement 3		3.2752	3.2547	-0.0205
Measurement 4		3.2752	3.2548	-0.0204
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2310	3.2079	-0.0231
Measurement 2		3.2310	3.2080	-0.0230
Measurement 3		3.2310	3.2079	-0.0231
Measurement 4		3.2310	3.2078	-0.0232
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2092	3.1971	-0.0121
Measurement 2		3.2093	3.1970	-0.0123
Measurement 3		3.2093	3.1970	-0.0123
Measurement 4		3.2094	3.1970	-0.0124
Average Measurements		***0-hrs.***	***750-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2399	3.2235	-0.0164
Transfer Pump Blade 2		3.2752	3.2548	-0.0204
Transfer Pump Blade 3		3.2310	3.2079	-0.0231
Transfer Pump Blade 4		3.2093	3.1970	-0.0123
	Roller to Roller (in)	1.9761	1.9757	-0.0004
	Eccentricity (in.)	0.0110	0.0100	-0.0010
	Drive Backlash (In)	0.0040	0.0050	0.0010

Table N-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438599	Test Number: 14	
Fuel Description : Jet A-1 w/50-mg/L OLI-9070x @ 170°F				
	Date:	3/4/2012	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.3060	3.2980	-0.0080
Measurement 2		3.3061	3.2979	-0.0082
Measurement 3		3.3060	3.2981	-0.0079
Measurement 4		3.3060	3.2980	-0.0080
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.3733	3.2615	-0.1118
Measurement 2		3.2734	3.2615	-0.0119
Measurement 3		3.2732	3.2615	-0.0117
Measurement 4		3.2732	3.2615	-0.0117
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2466	3.2354	-0.0112
Measurement 2		3.2465	3.2353	-0.0112
Measurement 3		3.2465	3.2352	-0.0113
Measurement 4		3.2465	3.2352	-0.0113
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2645	3.2538	-0.0107
Measurement 2		3.2645	3.2537	-0.0108
Measurement 3		3.2644	3.2537	-0.0107
Measurement 4		3.2644	3.2538	-0.0106
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.3060	3.2980	-0.0080
Transfer Pump Blade 2		3.2983	3.2615	-0.0368
Transfer Pump Blade 3		3.2465	3.2353	-0.0113
Transfer Pump Blade 4		3.2645	3.2538	-0.0107
	Roller to Roller (in)	1.9761	1.9758	-0.0003
	Eccentricity (in.)	0.0060	0.0060	0.0000
	Drive Backlash (In)	0.0050	0.0160	0.0110

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table N-6.

Table N-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection												
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
14	15438598	Jet A-1 w/50-mg/L OLI-9070x @ 170°F	14-1	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			14-2	2200	1925	Pass	Pass	Pass	Pass	Pass	Pass
			14-3	2150	1975	Pass	Pass	Pass	Pass	Pass	Pass
			14-4	2125	1975	Pass	Pass	Pass	Pass	Pass	Pass
			14-5	2150	1950	Pass	Pass	Pass	Pass	Pass	Pass
			14-6	2075	1875	Pass	Pass	Pass	Pass	Pass	Pass
			14-7	2150	1925	Pass	Pass	Pass	Pass	Pass	Pass
			14-8	2125	1975	Pass	Pass	Pass	Pass	Pass	Pass
14	15438599	Jet A-1 w/50-mg/L OLI-9070x @ 170°F	14-11	2175	1900	Pass	Pass	Pass	Pass	Pass	Pass
			14-12	2175	1900	Pass	Pass	Pass	Pass	Pass	Pass
			14-13	2175	1950	Pass	Pass	Pass	Pass	Pass	Pass
			14-14	2100	1950	Pass	Pass	Pass	Pass	Pass	Pass
			14-15	2100	1925	Pass	Pass	Pass	Pass	Pass	Pass
			14-16	2125	1825	Pass	Pass	Pass	Pass	Pass	Pass
			14-17	2150	1925	Pass	Pass	Pass	Pass	Pass	Pass
			14-18	2175	1900	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table N-7 and Table N-8.

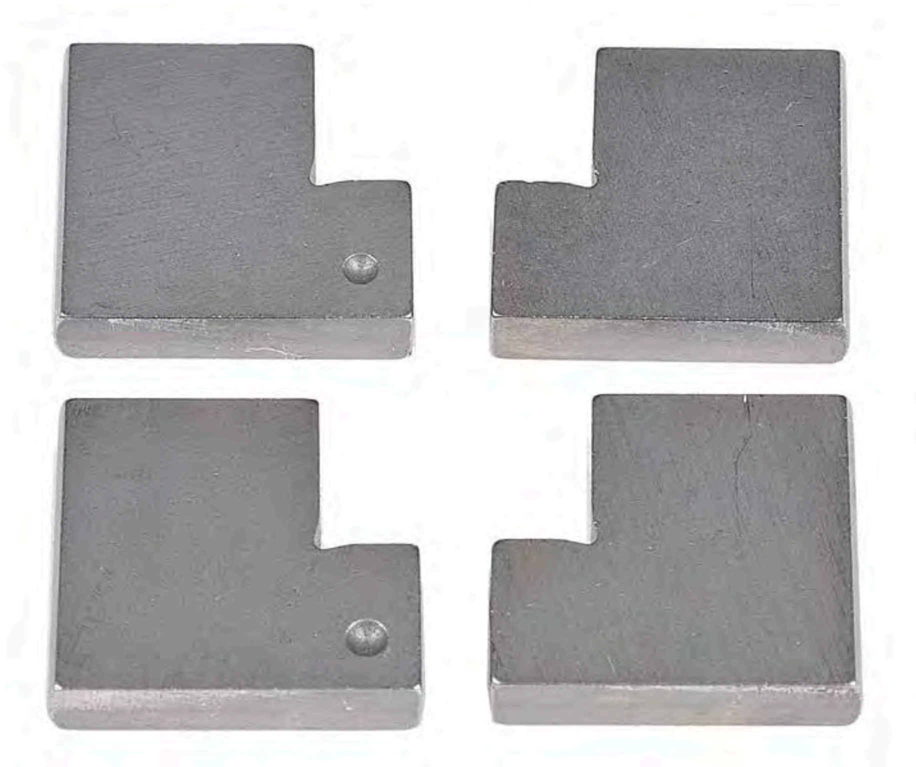
Table N-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438598
Test Condition : Jet A-1 w/50-mg/L OLI-9070x @ 170°F		Pump Duration : 750.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Light wear at rotor slots and liner contact	1.5
BLADE SPRINGS	Light rubbing wear	1
LINER	Wear on 60% of Liner	3
TRANSFER PUMP REGULATOR	Wear mark from rotor and polishing wear	2
REGULATOR PISTON	Wear scar and light polishing	2.5
ROTOR	Light polishing at distributor ports	1
ROTOR RETAINERS	wear from rotor contacts	2.5
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Polishing wear	2.5
SHOES	Dimple on back. Light wear marks from leaf spring	2
ROLLERS	Some scarring, pitting and discoloration	3
LEAF SPRING	Wear from shoe contact	2
CAM RING	Wear from rollor contact	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Light wear from governor arm fingers	1.5
GOVORNER WEIGHTS	Wear from thrust washer contact	1.5
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Wear from roller contact	2
DRIVE SHAFT SEALS	Heat from failed shaft needle bearing caused seals to disintegrate	5
CAM PIN	Normal. In spec	1
ADVANCE PISTON	Scarring wear	3
HOUSING	Bearing failed	5
	AVERAGE DEMERIT RATINGS	2.087

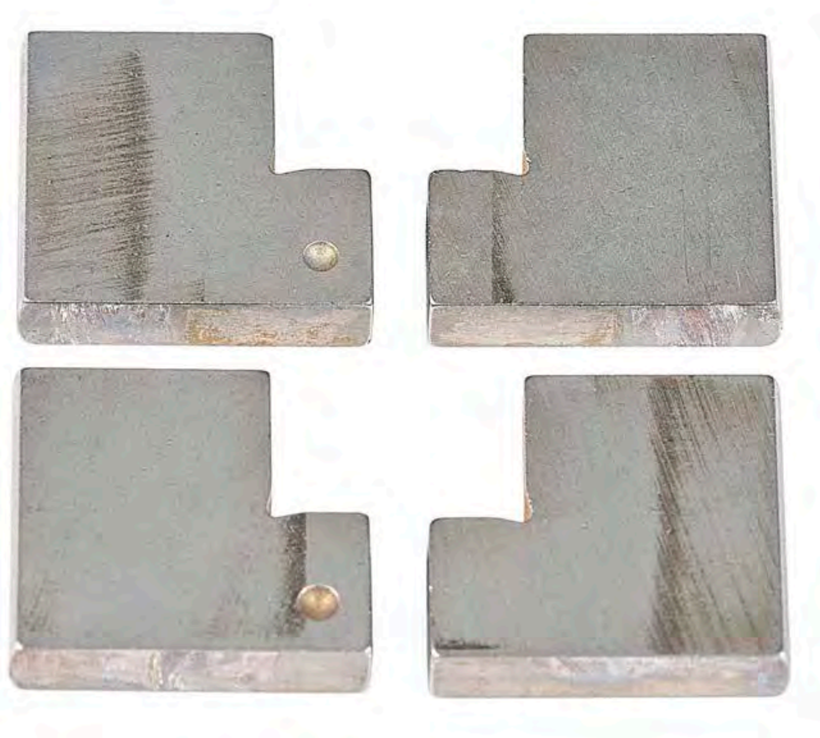
Table N-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438599
Test Condition : Jet A-1 w/50-mg/L OLI-9070x @ 170°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Light wear at rotor slots and liner contact	1.5
BLADE SPRINGS	Light rubbing wear	1
LINER	Wear on 60% of Liner	2.5
TRANSFER PUMP REGULATOR	Wear mark from rotor and polishing wear	2
REGULATOR PISTON	Polishing wear	1.5
ROTOR	Light polishing at distributor ports	1.5
ROTOR RETAINERS	Wear from rotor contact	2.5
DELIVERY VALVE	Broken springs. Heavy polishing wear	2.5
PLUNGERS	Heavy polishing wear. Slight scuffing	2.5
SHOES	Dimple wear marks from leaf spring. Scorring from rollers	2.5
ROLLERS	Light pitting and discoloration. Light scorring	3
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Wear from rollor contact	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Light wear from governor arm fingers	1.5
GOVORNER WEIGHTS	Wear from thrust washer contact	2
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Wear from roller contact	2.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	In spec	1
ADVANCE PISTON	Scuffing wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.761

PHOTOGRAPHS FOR LEFT PUMP



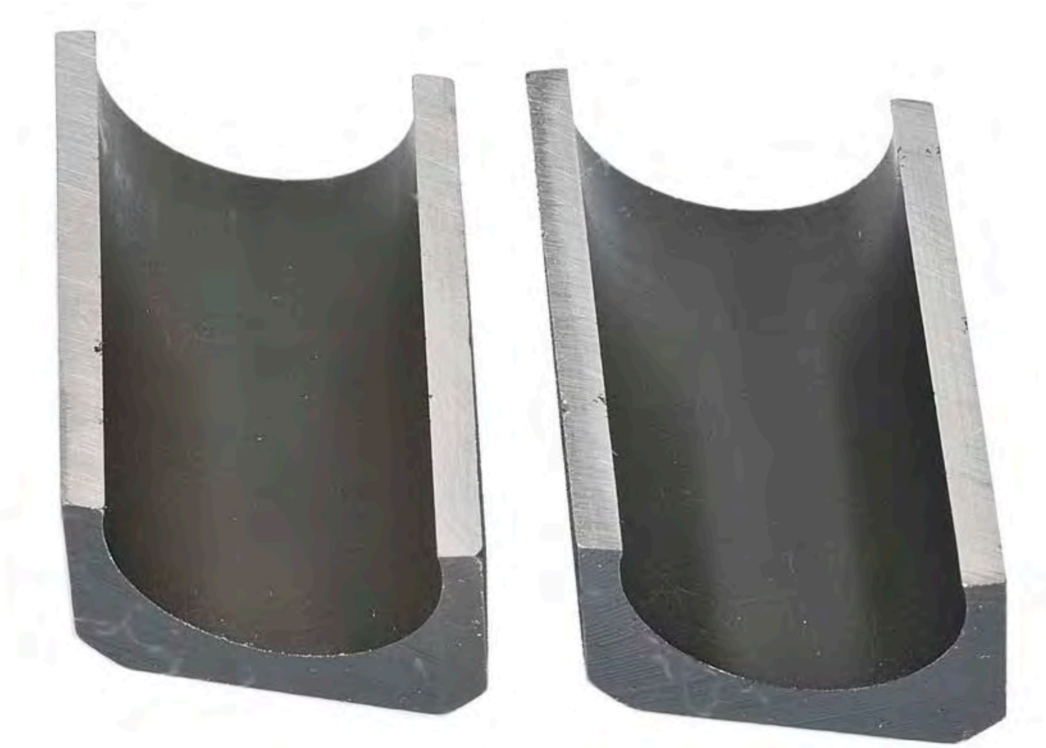
SN15438598 Transfer Pump Blades (Side), Before



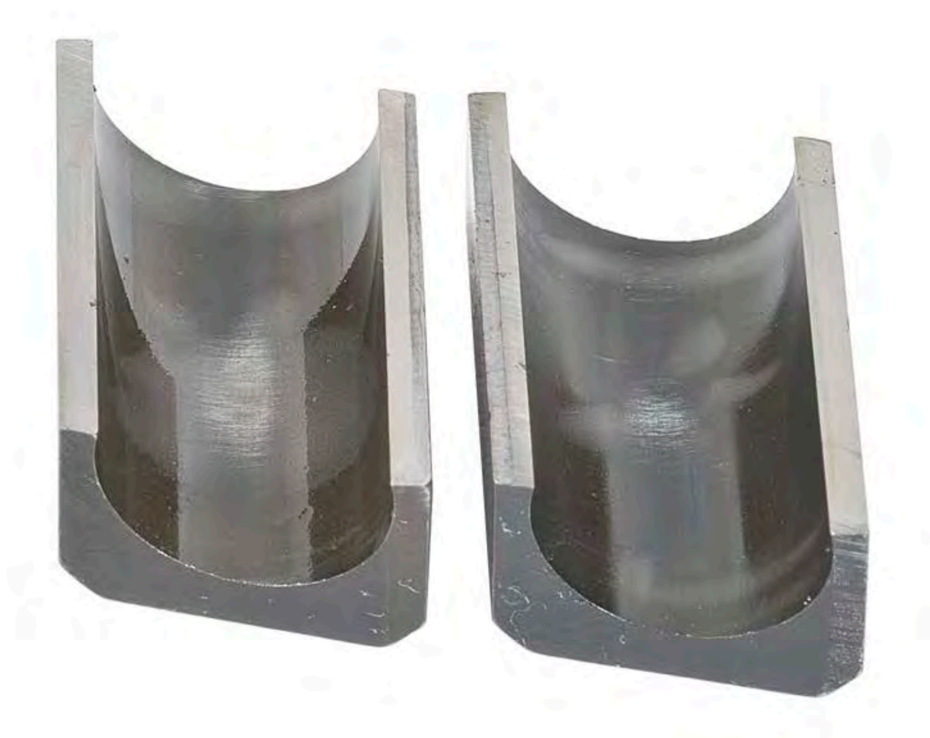
SN15438598 Transfer Pump Blades (Side), After

SN15438598 Transfer Pump Blades (Profile), Before

SN15438598 Transfer Pump Blades (Profile), After



SN15438598 Shoes (Front), Before



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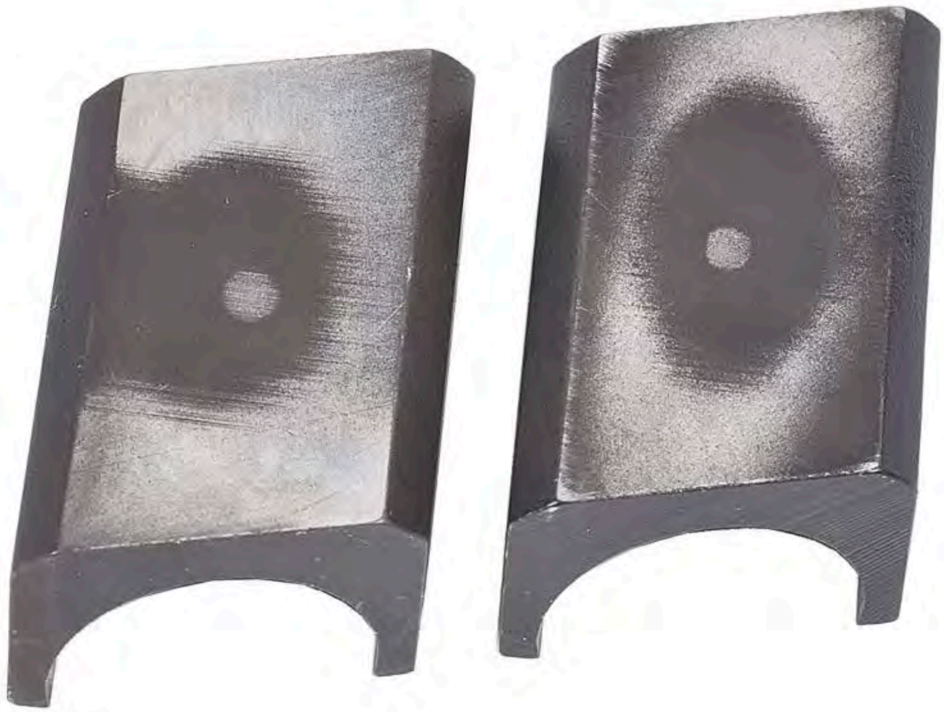
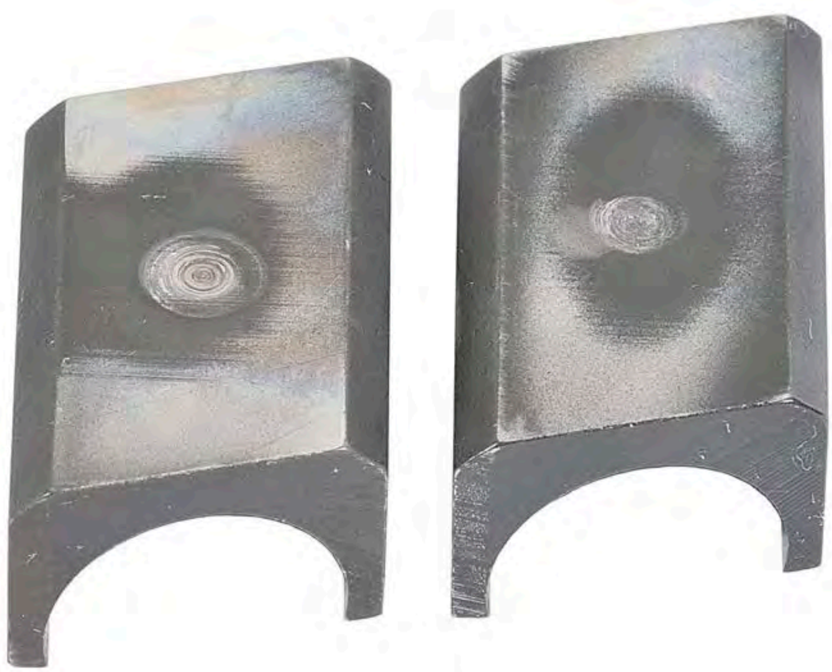


SN15438598 Shoes (Back), Before



SN15438598 Shoes (Back), After

SN15438598 Rollers, Before

SN15438598 Rollers, After

SN15438598 Piston Plungers, Before

SN15438598 Piston Plungers, After

SN15438598 Thrust Washer, Before

SN15438598 Thrust Washer, After

SN15438598 Governor Weight, Before

SN15438598 Governor Weight, After

SN15438598 Cam Ring, Before

SN15438598 Cam Ring, After

SN15438598 Eccentric Ring, Before

SN15438598 Eccentric Ring, After

SN15438598 Rotor (Front), Before

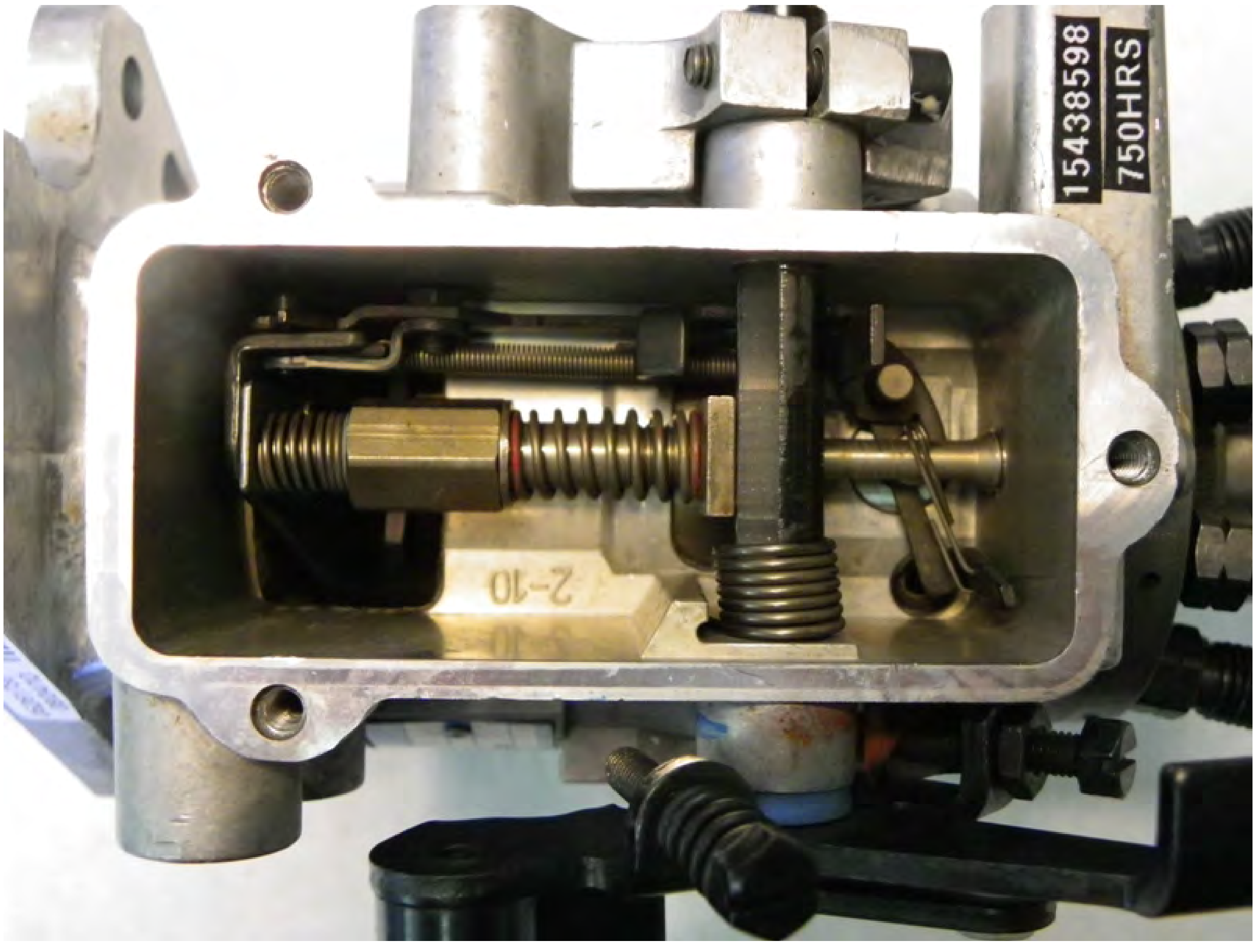
SN15438598 Rotor (Front), After

SN15438598 Rotor (Back), Before

SN15438598 Rotor (Back), After

SN15438598 Drive Tang, Before

SN15438598 Drive Tang, After

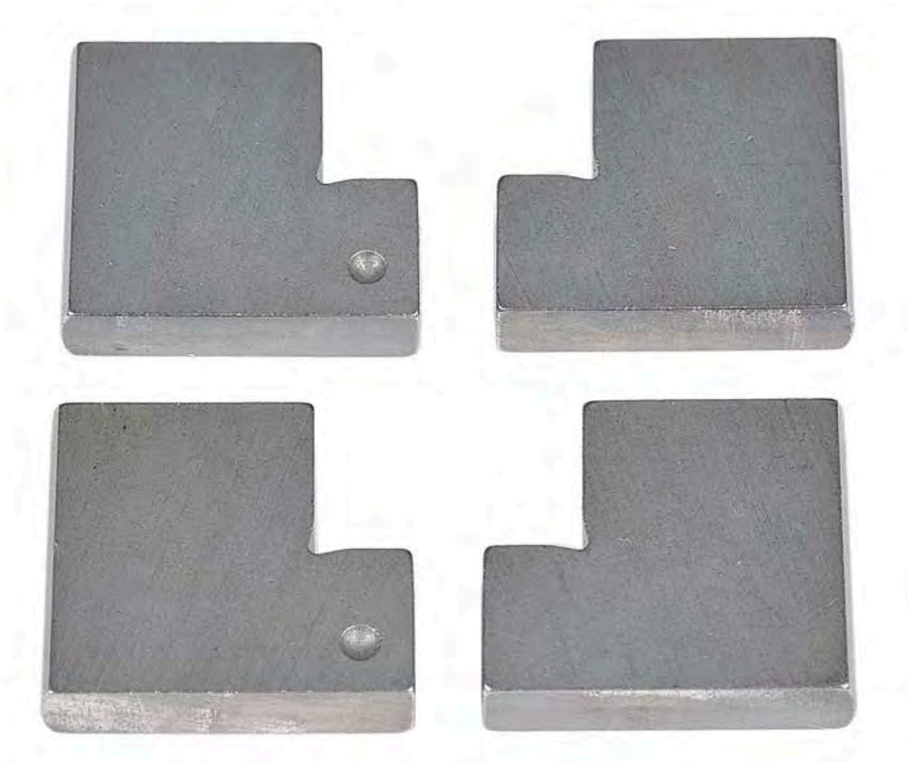


SN15438598 Governor Assembly, After

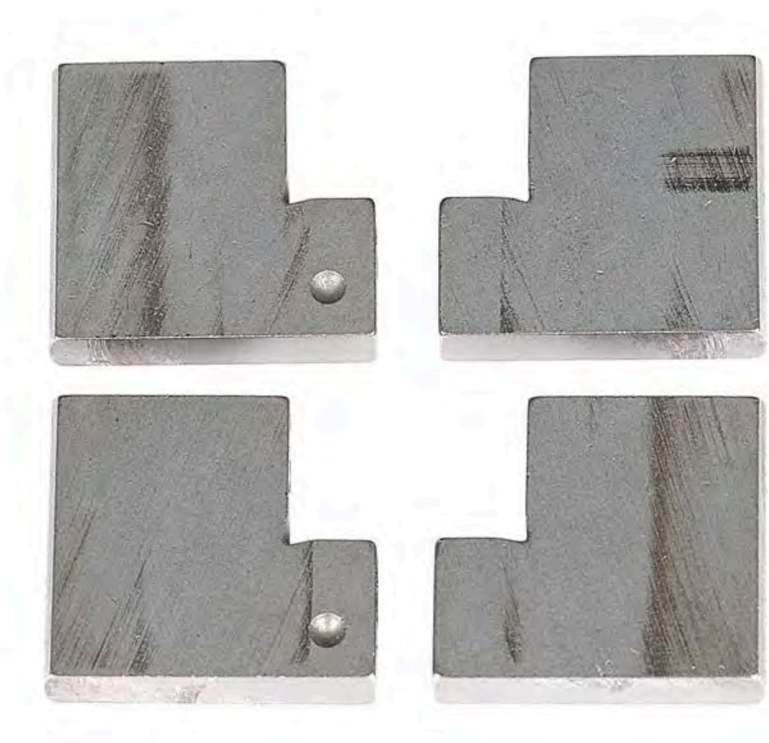
SN15438598 Post-Test Drive Shaft Assembly

SN15438598 Post-Test Pump Housing Assembly

PHOTOGRAPHS FOR RIGHT PUMP



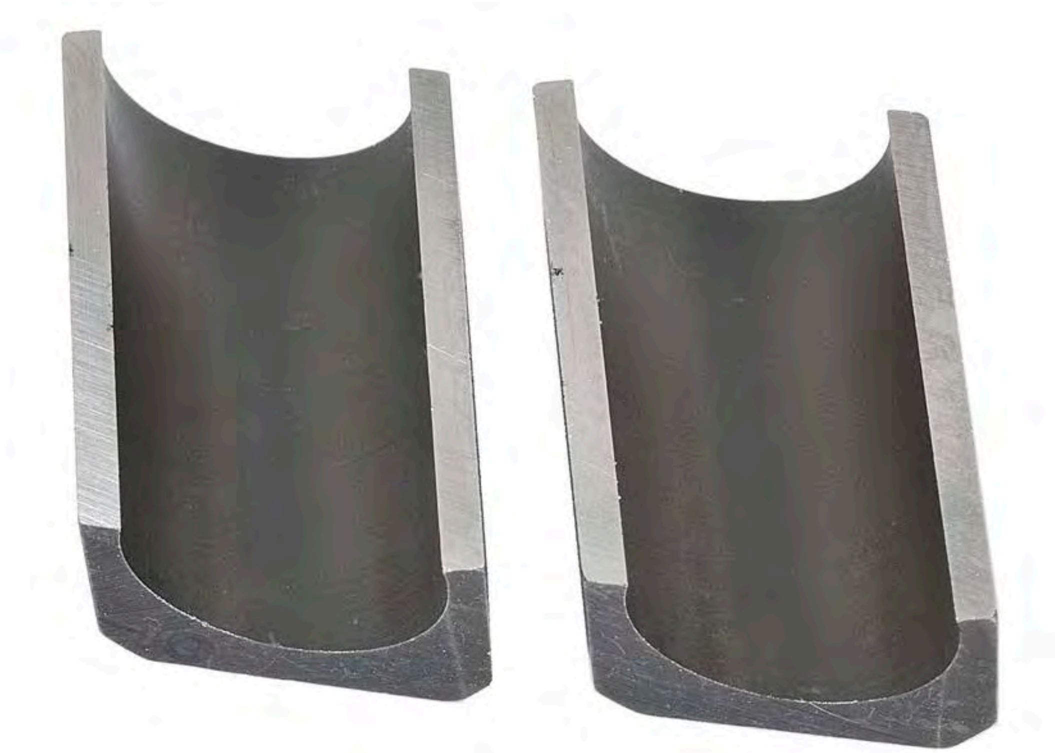
SN15438599 Transfer Pump Blades, Before



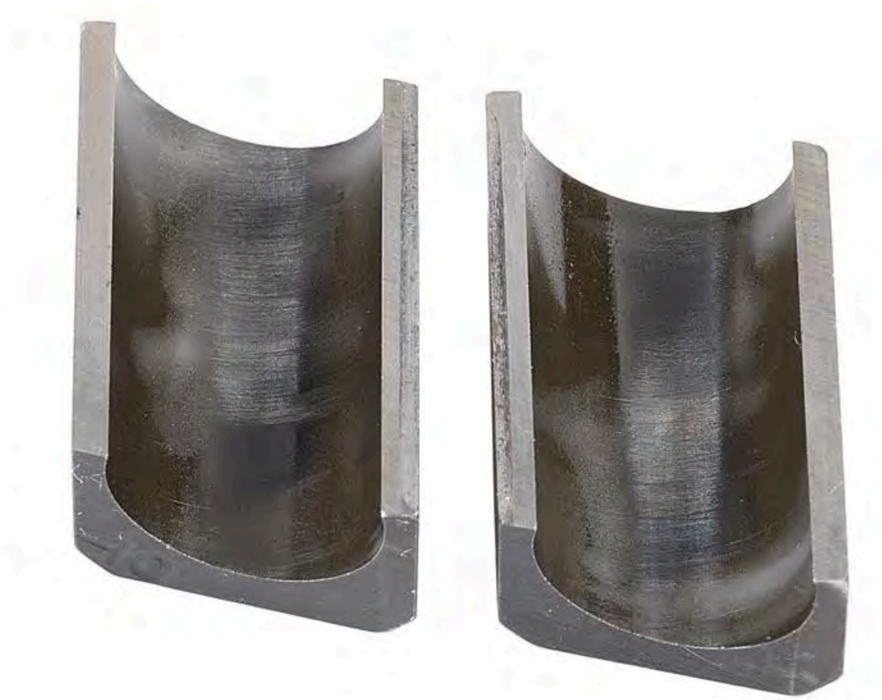
SN158599 Transfer Pump Blades, After

SN15438599 Transfer Pump Blades (Profile), Before

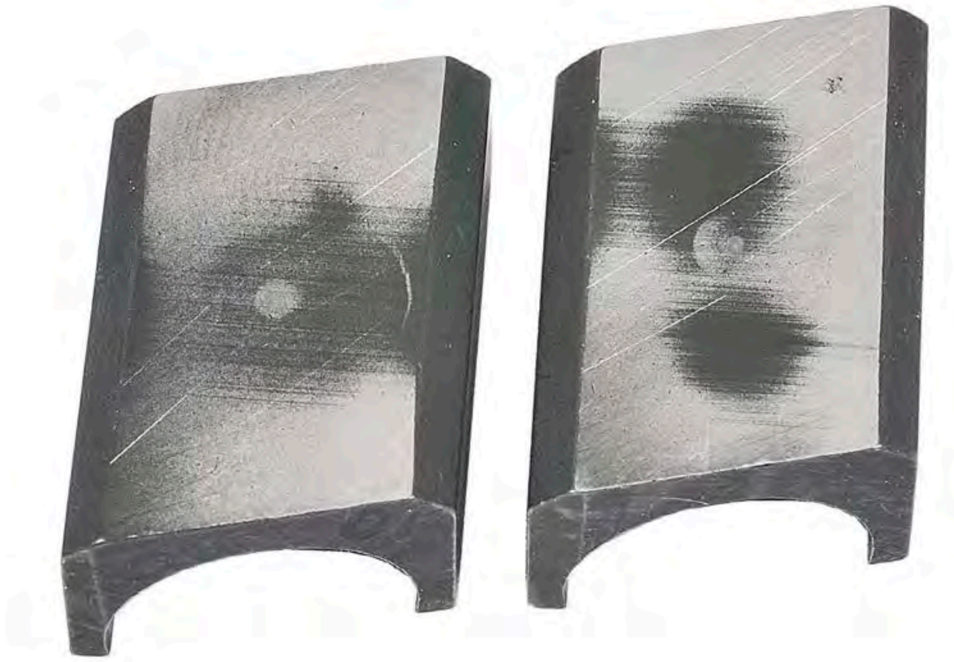
SN15438599 Transfer Pump Blades (Profile), After



SN15438599 Shoes (Front), Before



SN15438599 Shoes (Front), After



SN15438599 Shoes (Back) Before

SN15438599 Shoes (Back), After

SN15438599 Rollers, Before

SN15438599 Rollers, After

SN15438599 Piston Plungers, Before

SN15438599 Piston Plungers, After

SN15438599 Thrust Washer, Before

SN15438599 Thrust Washer, After

SN15438599 Governor Weight, Before

SN15438599 Governor Weight, After

SN15438599 Cam Ring, Before

SN15438599 Cam Ring, After

SN15438599 Eccentric Ring, Before

SN15438599 Eccentric Ring, After


SN15438599 Rotor (Front), Before

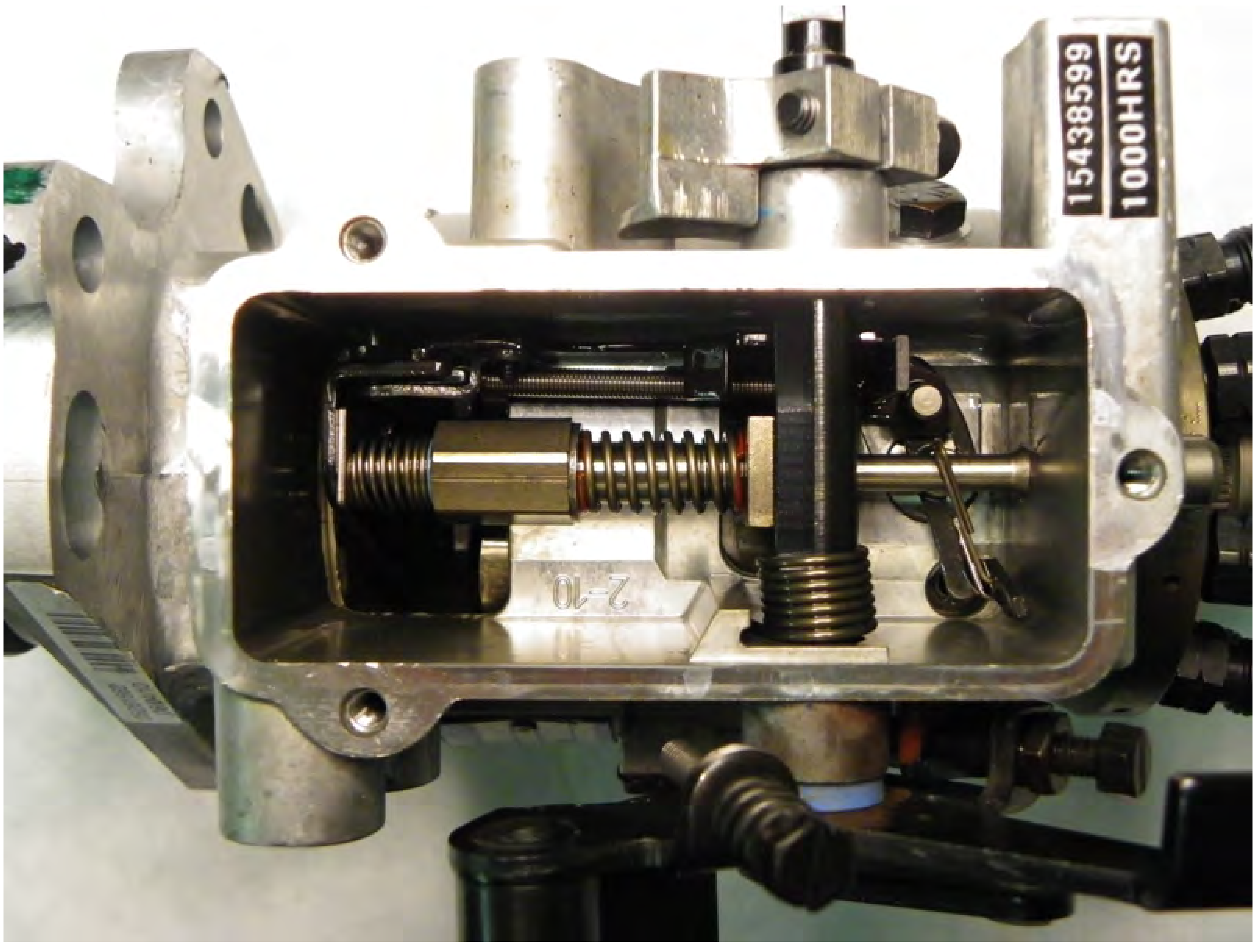

SN15438599 Rotor (Front), After

SN15438599 Rotor (Back), Before

SN15438599 Rotor (Back), After

SN15438599 Drive Tang, Before

SN15438599 Drive Tang, After



SN15438599 Governor Assembly, After

APPENDIX O

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: FT-SPK w/o CI/LI
Test Number: C3T15-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: FT-SPK w/o CI/LI

Test Fuel ID: AL27892

Test Temperature: 40°C (105°F)

Test Number: C3T15-40-1000

Start of Test Date: November 14, 2011

End of Test Date: November 16, 2011

Test Duration: 48.13 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure O-1.

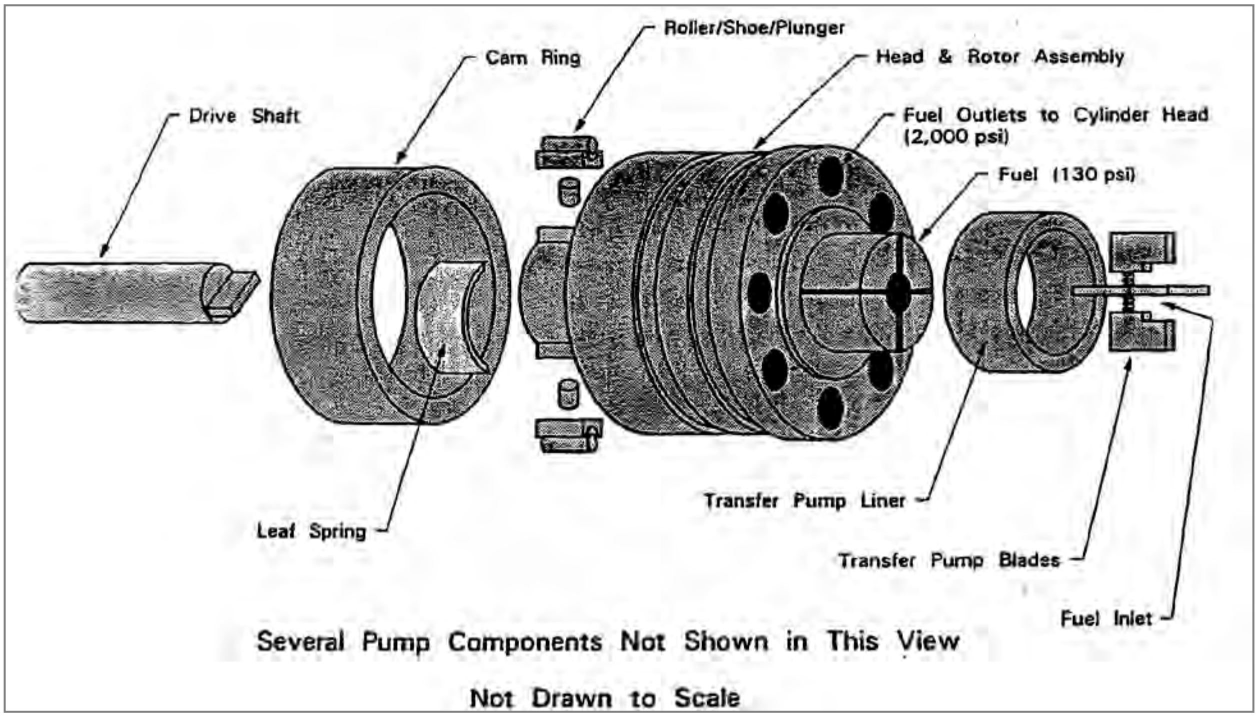


Figure O-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table O-1.

Table O-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40° +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table O-2.

Table O-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	2.23
FLO_R	Injected Flow-rate [mL/min]	804	46.4
FUELIN_P	Fuel Inlet Pressure [psig]	3	0.24
TRNS_P_R	Transfer Pump Pressure [psig]	69.88	1.24
HSG_P_R	Pump Housing Pressure [psig]	10.8	1.08
RTRN_T_R	Fuel Return Temperature [°C]	49	2.41
FUEL_T	Fuel Tank Temperature [°C]	83.9	217.4
FUELIN_T	Fuel Inlet Temperature [°C]	40	0.89

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure O-2 through Figure O-4.

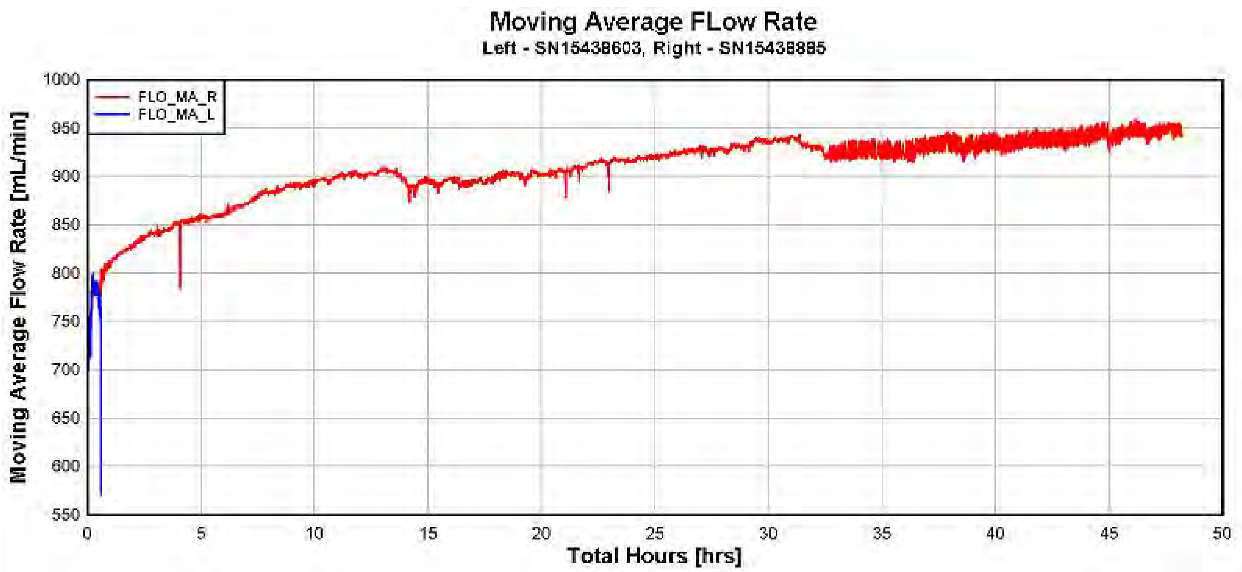


Figure O-2. Pump Flow, Moving Average

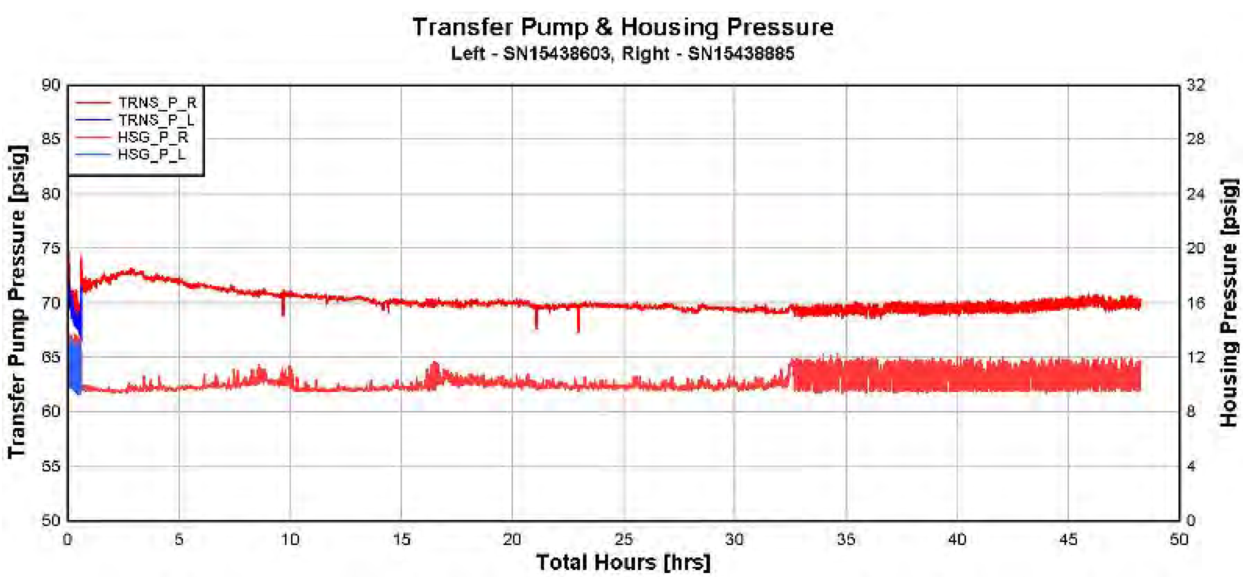


Figure O-3. Transfer Pump & Housing Pressure

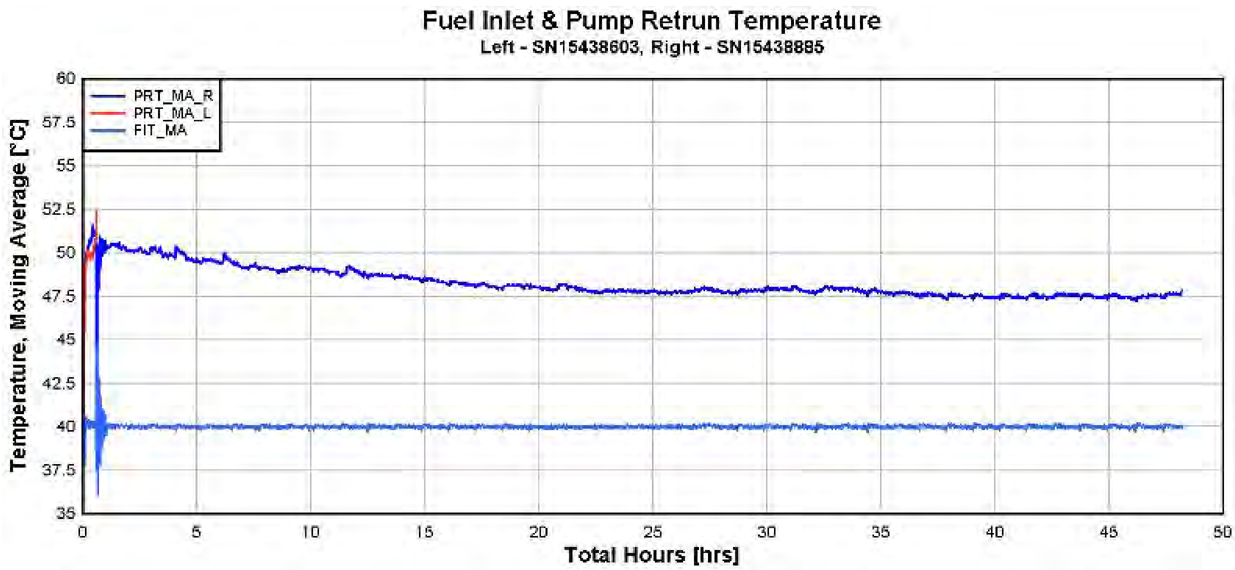


Figure O-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table O-3. (Note – Calibration data to be used as reference only).

Table O-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 15			Test Duration : 1000-hrs.		
Test Fuel :	FT-SPK @ 105°F			SN : 15438603			SN : 15438885		
PUMP RPM	Description	Specification		Pump Duration : 0.59-hrs.			Pump Duration : 48.-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	ND		62 psi	ND	
	Return Fuel	225 cc	375 cc	342 cc	ND		360 cc	ND	
350	Low Idle	12 cc	16 cc	14 cc	ND		15 cc	ND	
	Housing psi.	8 psi	12 psi	10.0 psi	ND		10.5 psi	ND	
	Advance	3.50°		5.20°	ND		4.20°	ND	
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	ND		.0 psi	ND	
750	Shut-Off		4.0 cc	.0 cc	ND		.0 cc	ND	
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	ND		67.0 cc	ND	
1600	WOT Fuel delivery	60 cc		64 cc	ND		63 cc	ND	
	WOT Advance	2.50°	3.50°	2.69°	ND		3.06°	ND	
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	ND		22.0 cc	ND	
	Face Cam Advance	5.25°	7.25°	6.00°	ND		6.84°	ND	
	Low Idle	11.0°	12.0°	**11.0°**	ND		11.1°	ND	
1825	Fuel Delivery	33 cc		39 cc	ND		39 cc	ND	
1950	High Idle		15 cc	2 cc	ND		3 cc	ND	
	Transfer pump psi.		125 psi	102 psi	ND		110 psi	ND	
200	WOT Fuel Delivery	58 cc		62 cc	ND		59 cc	ND	
	WOT Shut-Off		4 cc	0 cc	ND		0 cc	ND	
75	Low Idle Fuel Delivery	37 cc		53 cc	ND		46 cc	ND	
	Transfer pump psi.	16 psi		30 psi	ND		22 psi	ND	
	Housing psi.	.0 psi	12 psi	8.0 psi	ND		9 psi	ND	
	Air Timing	-1.00°	.00°	-.50°	ND		-.50°	ND	

Bold numbers = out of specification results

Notes : Pump SN:15438603-Rotary pump siezed 35 minutes into the test. No post-test pump calibration performed.

Pump SN:15438885-Rotary pump siezed 48 hours into the test. No post-test pump calibration performed.

ND=Not Determined

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table O-4 and Table O-5.

Table O-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438603	Test Number: 15	
Fuel Description : FT-SPK @ 105°F				
	Date:	1/0/1900	5/11/2012	
Transfer Pump Blade 1		***0-hrs.***	***0.59-hrs.***	***Change***
Measurement 1	Mass (g)	3.2807	3.2673	-0.0134
Measurement 2		3.2809	3.2674	-0.0135
Measurement 3		3.2809	3.2672	-0.0137
Measurement 4		3.2809	3.2672	-0.0137
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2966	3.2770	-0.0196
Measurement 2		3.2965	3.2770	-0.0195
Measurement 3		3.2963	3.2771	-0.0192
Measurement 4		3.2965	3.2771	-0.0194
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2362	3.2135	-0.0227
Measurement 2		3.2362	3.2134	-0.0228
Measurement 3		3.2361	3.2134	-0.0227
Measurement 4		3.2361	3.2134	-0.0227
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2730	3.2532	-0.0198
Measurement 2		3.2730	3.2530	-0.0200
Measurement 3		3.2729	3.2531	-0.0198
Measurement 4		3.2730	3.2531	-0.0199
Average Measurements		***0-hrs.***	***0.59-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2809	3.2673	-0.0136
Transfer Pump Blade 2		3.2965	3.2771	-0.0194
Transfer Pump Blade 3		3.2362	3.2134	-0.0227
Transfer Pump Blade 4		3.2730	3.2531	-0.0199
	Roller to Roller (in)	1.9760	0.0000	-1.9760
	Eccentricity (in.)	0.0040	0.0000	-0.0040
	Drive Backlash (In)	0.0035	0.0000	-0.0035

Table O-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438885	Test Number: 15	
Fuel Description : FT-SPK @ 105°F				
	Date:	1/0/1900	5/11/2012	
Transfer Pump Blade 1		***0-hrs.***	***48-hrs.***	***Change***
Measurement 1	Mass (g)	3.2934	3.2770	-0.0164
Measurement 2	Mass (g)	3.2931	3.2771	-0.0160
Measurement 3	Mass (g)	3.2931	3.2770	-0.0161
Measurement 4	Mass (g)	3.2932	3.2770	-0.0162
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2389	3.2256	-0.0133
Measurement 2	Mass (g)	3.2388	3.2254	-0.0134
Measurement 3	Mass (g)	3.2389	3.2254	-0.0135
Measurement 4	Mass (g)	3.2387	3.2253	-0.0134
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2808	3.2667	-0.0141
Measurement 2	Mass (g)	3.2807	3.2665	-0.0142
Measurement 3	Mass (g)	3.2807	3.2665	-0.0142
Measurement 4	Mass (g)	3.2807	3.2665	-0.0142
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2207	3.2045	-0.0162
Measurement 2	Mass (g)	3.2207	3.2045	-0.0162
Measurement 3	Mass (g)	3.2208	3.2045	-0.0163
Measurement 4	Mass (g)	3.2208	3.2045	-0.0163
Average Measurements		***0-hrs.***	***48-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2932	3.2770	-0.0162
Transfer Pump Blade 2	Mass (g)	3.2388	3.2254	-0.0134
Transfer Pump Blade 3	Mass (g)	3.2807	3.2666	-0.0142
Transfer Pump Blade 4	Mass (g)	3.2208	3.2045	-0.0163
	Roller to Roller (in)	1.9764	0.0000	-1.9764
	Eccentricity (in.)	0.0130	0.0000	-0.0130
	Drive Backlash (In)	0.0060	0.0000	-0.0060

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table O-6.

Table O-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
15	15438603	FT-SPK @ 105°F	15-1	2175	2150	Pass	Pass	Pass	Pass	Pass	Pass
			15-2	2125	2125	Pass	Pass	Pass	Pass	Pass	Pass
			15-3	2200	2125	Pass	Pass	Pass	Pass	Pass	Pass
			15-4	2125	2125	Pass	Pass	Pass	Pass	Pass	Pass
			15-5	2175	2125	Pass	Pass	Pass	Pass	Pass	Pass
			15-6	2125	2125	Pass	Pass	Pass	Pass	Pass	Pass
			15-7	2125	2125	Pass	Pass	Pass	Pass	Pass	Pass
			15-8	2200	2150	Pass	Pass	Pass	Pass	Pass	Pass
15	15438885	FT-SPK @ 105°F	15-11	2125	1950	Pass	Pass	Pass	Pass	Pass	Pass
			15-12	2125	1975	Pass	Pass	Pass	Pass	Pass	Pass
			15-13	2125	1950	Pass	Pass	Pass	Pass	Pass	Pass
			15-14	2075	1900	Pass	Pass	Pass	Pass	Pass	Pass
			15-15	2150	1950	Pass	Pass	Pass	Pass	Pass	Pass
			15-16	2150	2025	Pass	Pass	Pass	Pass	Pass	Pass
			15-17	2125	1975	Pass	Pass	Pass	Pass	Pass	Pass
			15-18	2125	1975	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table O-7 and Table O-8.

Table O-7. Stanadyne Left Pump Parts Evaluation

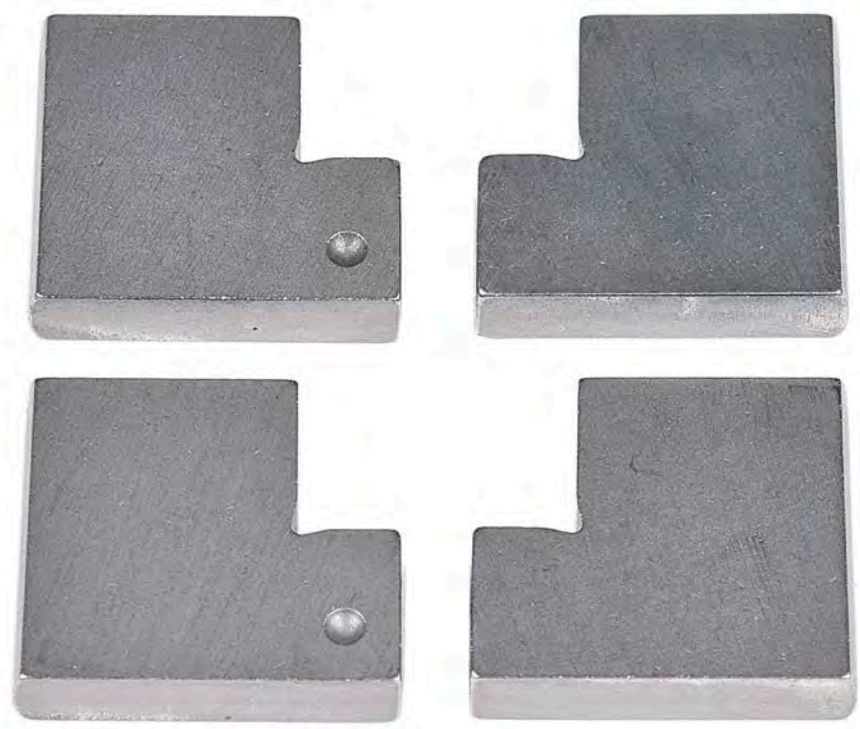
Pump Type : DB2831-5079		SN: 15438603
Test Condition : FT-SPK @ 105°F		Pump Duration : 0.59-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2
BLADE SPRINGS	Rubbing wear	1
LINER	Wear on 90% of surface. Scorring	3.5
TRANSFER PUMP REGULATOR	Scorring from rotor	3
REGULATOR PISTON	Light polishing wear	1
ROTOR	Seized	5
ROTOR RETAINERS	Scorring wear	3.5
DELIVERY VALVE	Light polishing wear	1
PLUNGERS	Polishing wear	1.5
SHOES	Dimple. Wear from leaf spring and scorring from rollers	3
ROLLERS	Light pitting and scorring	2.5
LEAF SPRING	Wear from contact from shoes	1
CAM RING	Polishing wear from rollors	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Light polishing from thrust washer contact	1
LINK HOOK	Normal	1
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Light polishing	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Some scorring wear	2.5
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.761

Table O-8. Stanadyne Right Pump Parts Evaluation

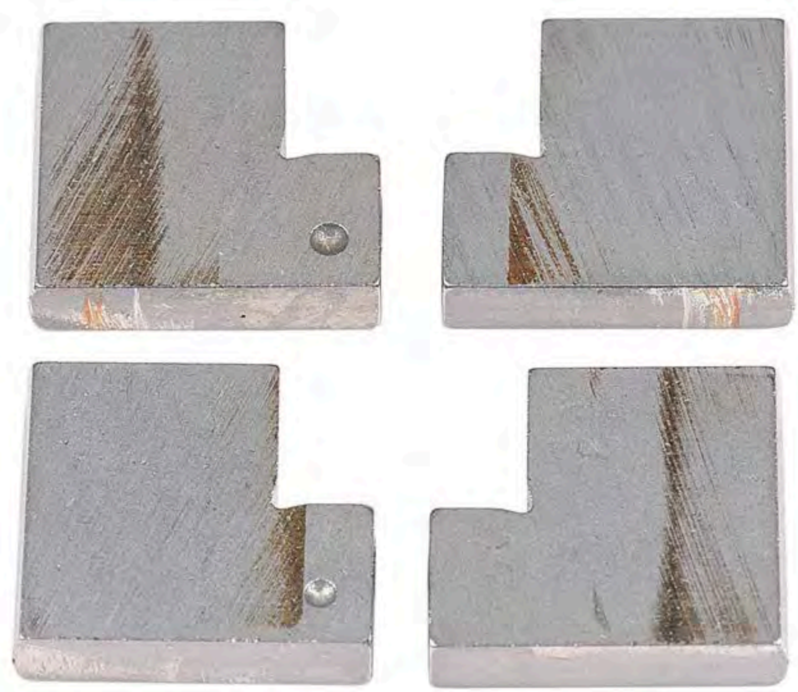
Pump Type : DB2831-5079	SN: 15438885
Test Condition : FT-SPK @ 105°F	Pump Duration : 48.-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Wear at rotor slots and liner contact	3
BLADE SPRINGS	Rubbing wear	2.5
LINER	Wear on 100% of surface. Heavy scorring	4.5
TRANSFER PUMP REGULATOR	Wear mark from rotor and polishing wear	2.5
REGULATOR PISTON	Polishing wear	1.5
ROTOR	Siezed	5
ROTOR RETAINERS	Scorring wear	3.5
DELIVERY VALVE	Light polishing	1
PLUNGERS	Polishing wear	1.5
SHOES	Dimple, wear from leaf spring, scoring from rollers	3
ROLLERS	Light pitting and scoring	2.5
LEAF SPRING	Wear from shoe contact	1
CAM RING	Polishing wear from rollers	1
THRUST WASHER	Polishing wear from weights	1
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Light polishing wear fromthrust washer contact	1
LINK HOOK	Normal	0.5
METERING VAVLE	Light polishing	1
DRIVE SHAFT TANG	Light polising	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal in spec	1
ADVANCE PISTON	Some scorring wear	2.5
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.891

PHOTOGRAPHS FOR LEFT PUMP



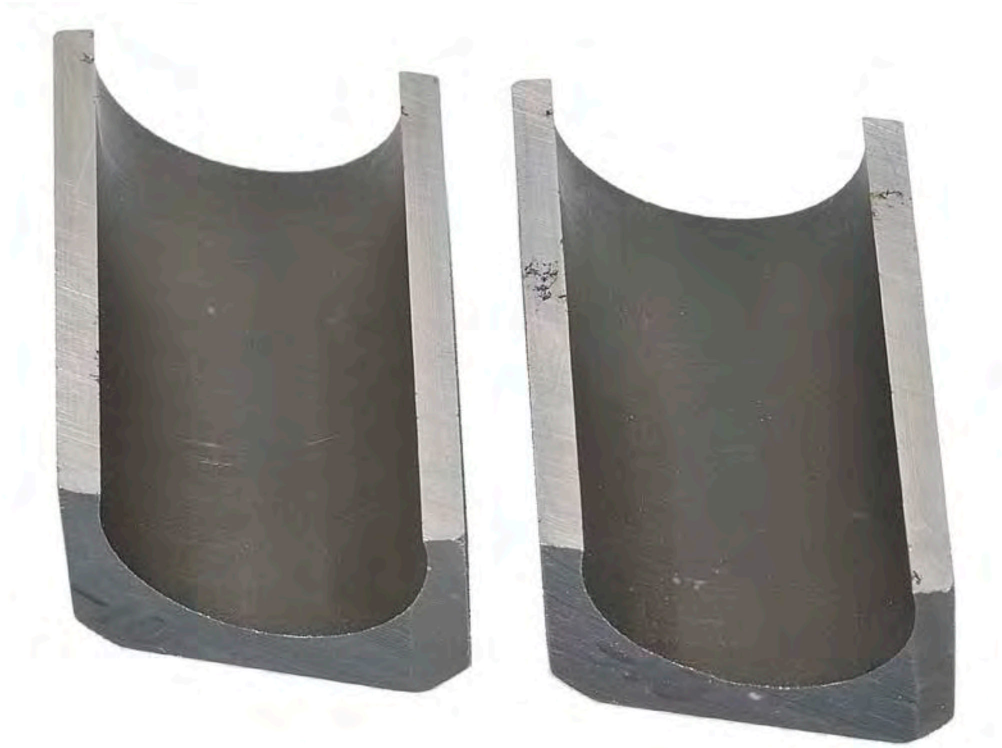
SN15438603 Transfer Pump Blades (Side), Before



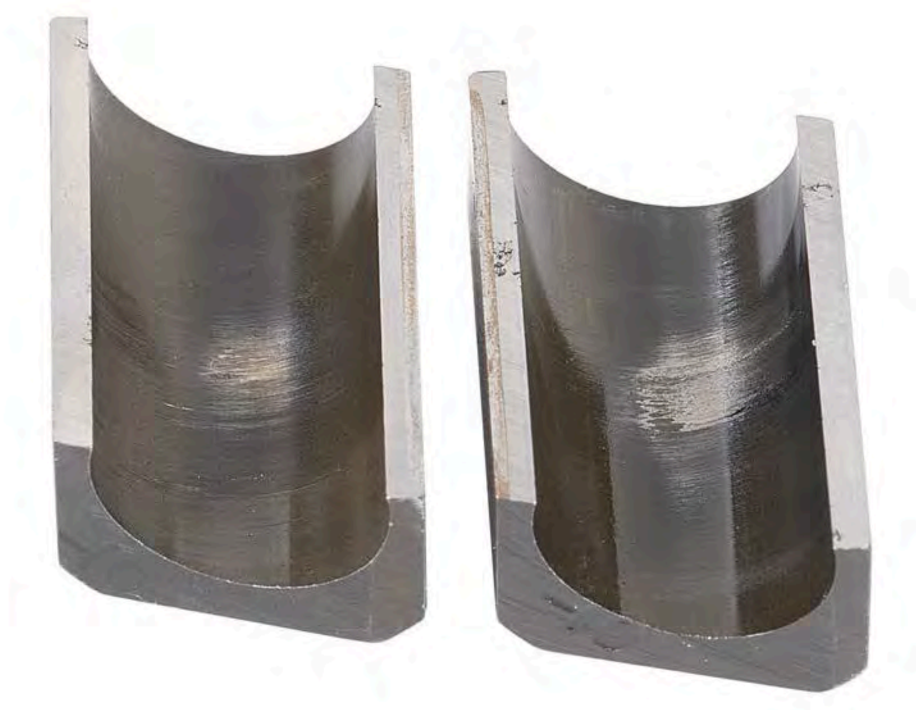
SN15438603 Transfer Pump Blades (Side), After

SN15438603 Transfer Pump Blades (Profile), Before

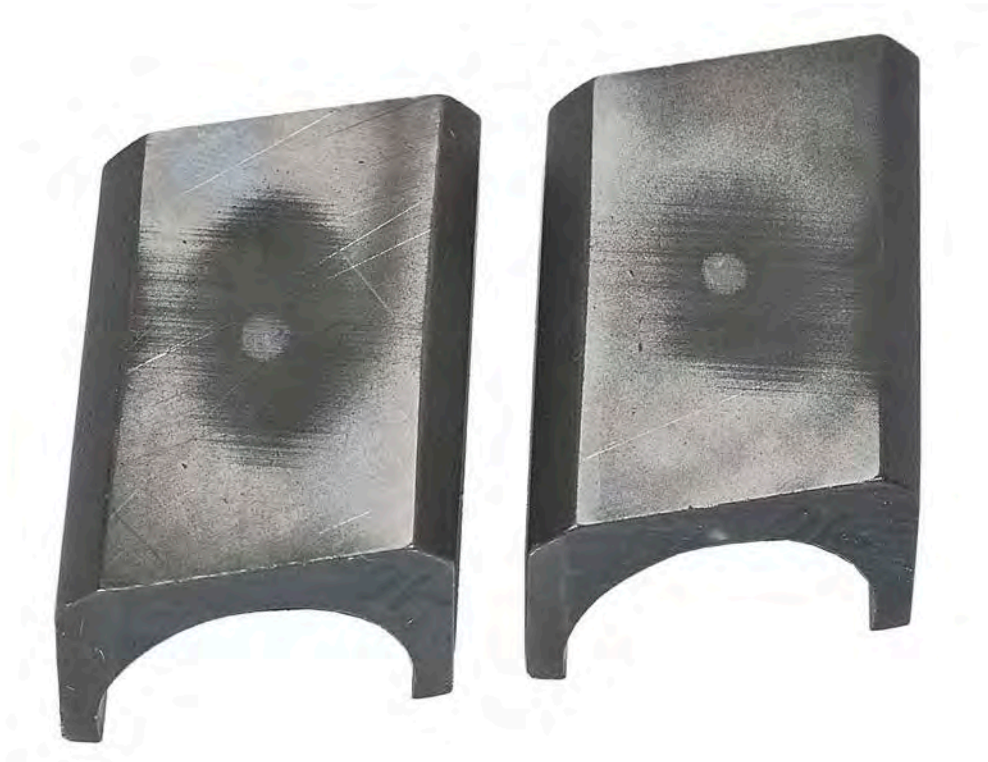
SN15438603 Transfer Pump Blades (Profile), After



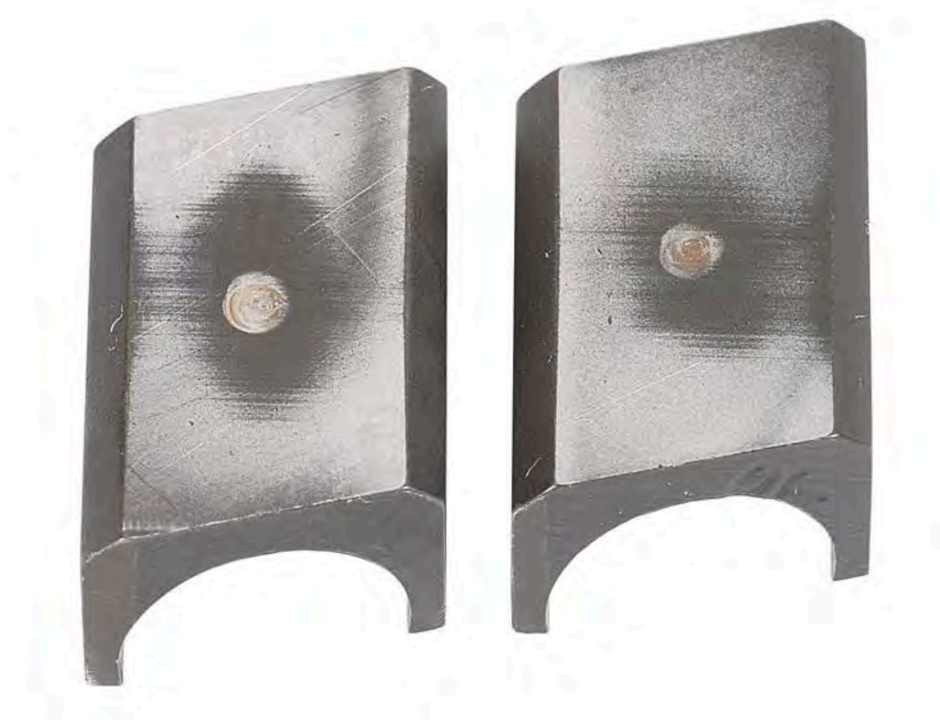
SN15438603 Shoes (Front), Before



SN15438603 Shoes (Front), After



SN15438603 Shoes (Back), Before



SN15438603 Shoes (Back), After

SN15438603 Rollers, Before

SN15438603 Rollers, After

SN15438603 Piston Plungers, Before

SN15438603 Piston Plungers, After

SN15438603 Thrust Washer, Before

SN15438603 Thrust Washer, After

SN15438603 Governor Weight, Before

SN15438603 Governor Weight, After

SN15438603 Cam Ring, Before

SN15438603 Cam Ring, After

SN15438603 Eccentric Ring, Before

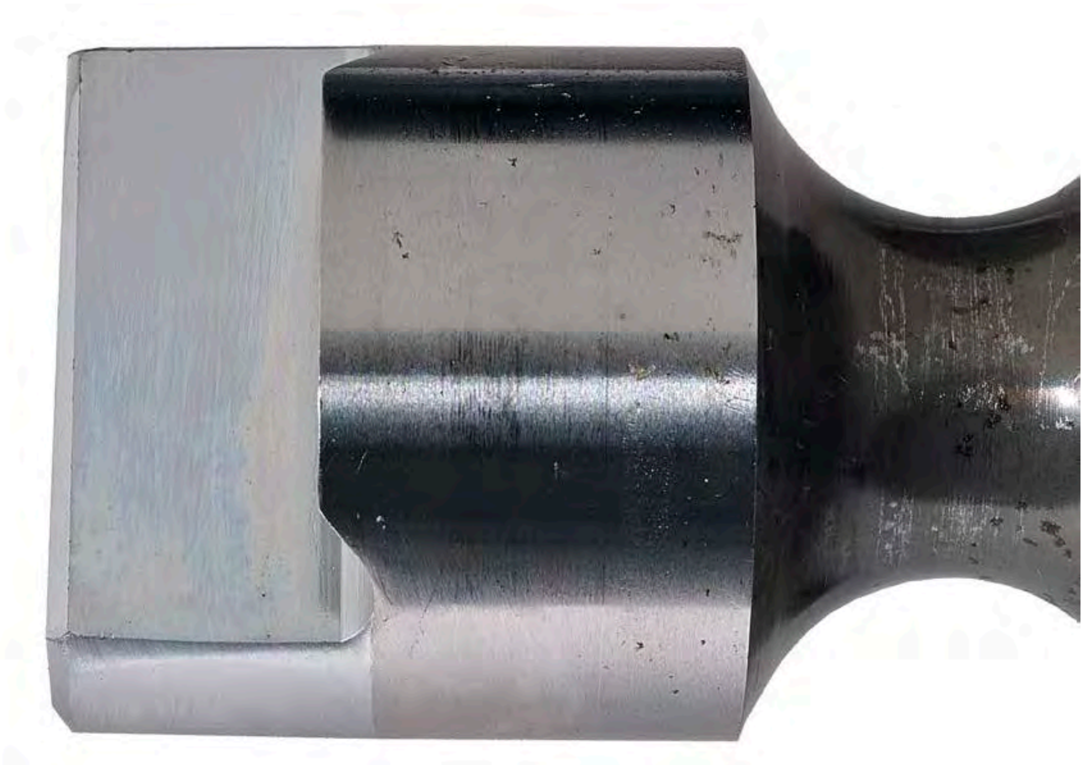
SN15438603 Eccentric Ring, After

SN15438603 Rotor (Front), Before

SN15438603 Rotor (Front), After

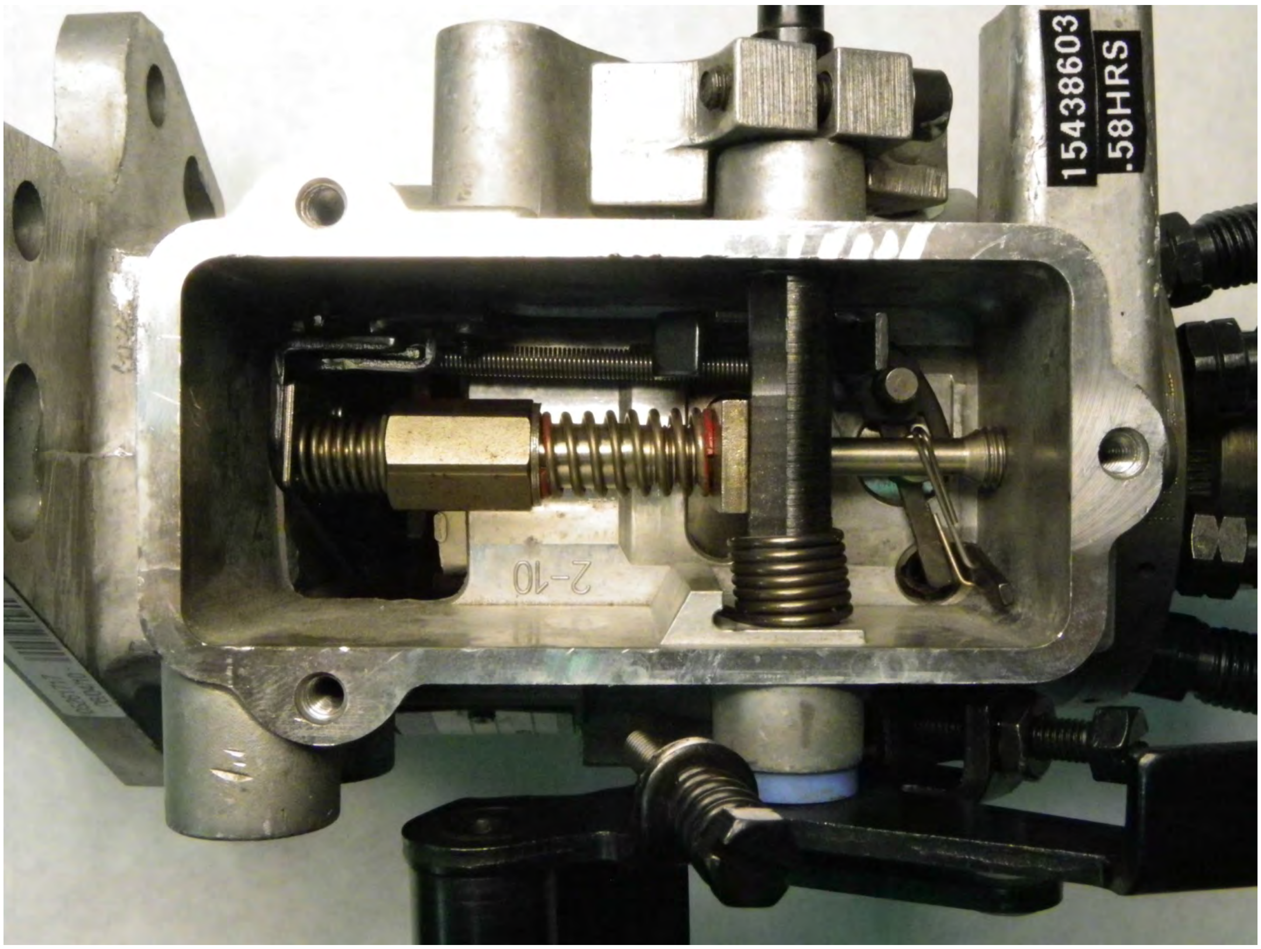
SN15438603 Rotor (Back), Before

SN15438603 Rotor (Back), After



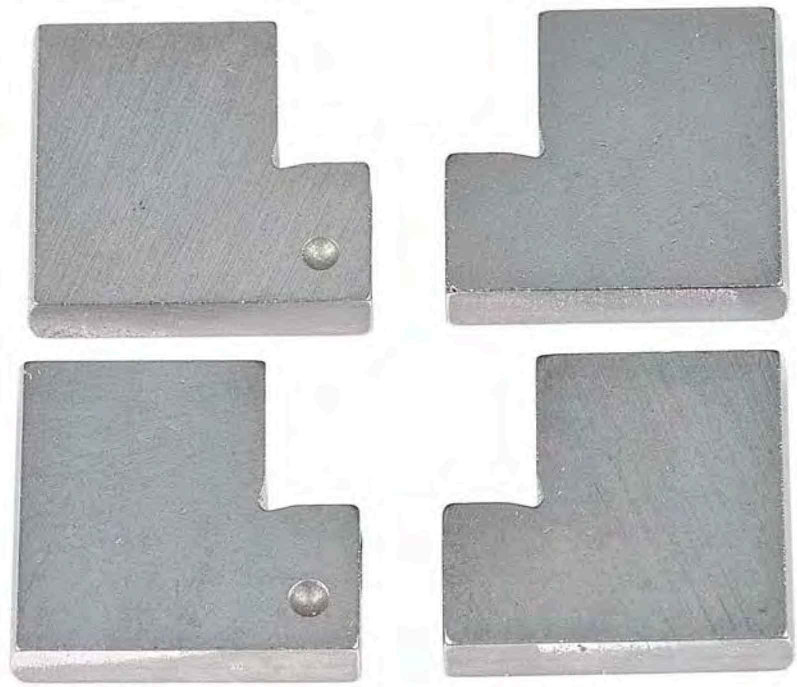
SN15438603 Drive Tang, Before

SN15438603 Drive Tang, After

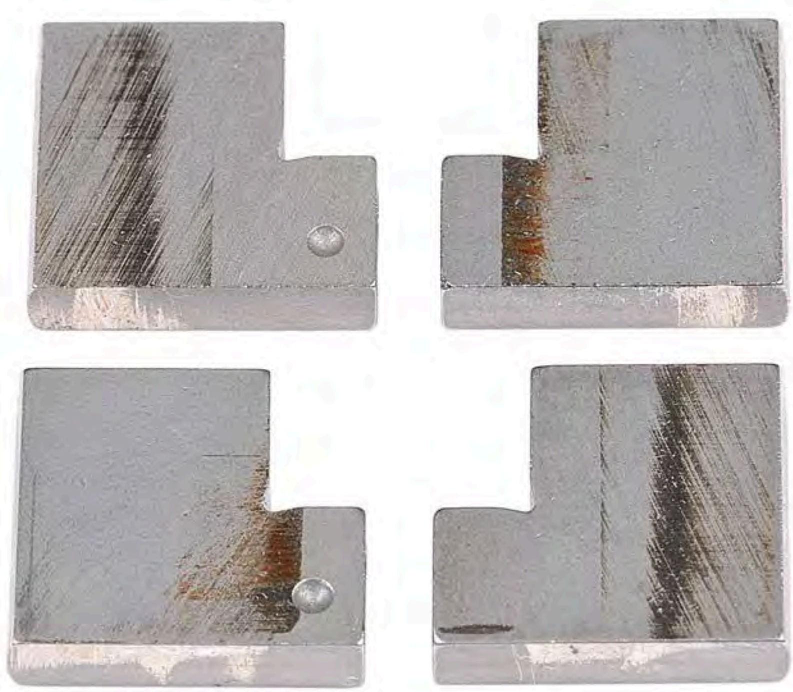


SN15438603 Governor Assembly

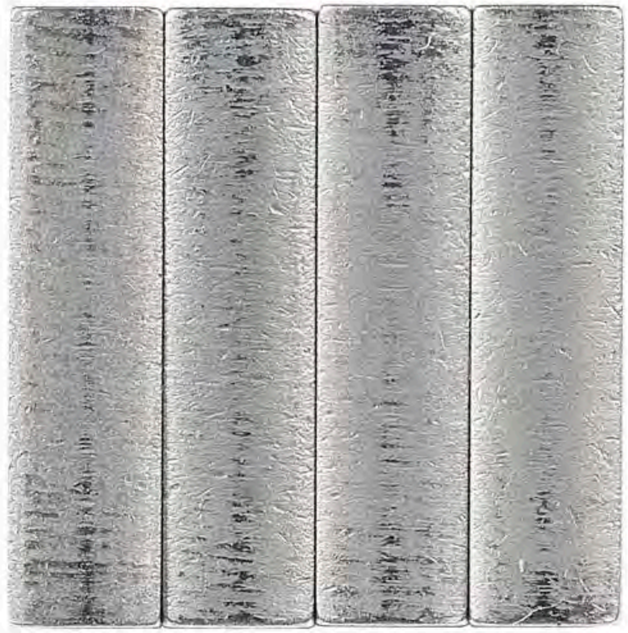
PHOTOGRAPHS FOR RIGHT PUMP



SN15438885 Transfer Pump Blades, Before

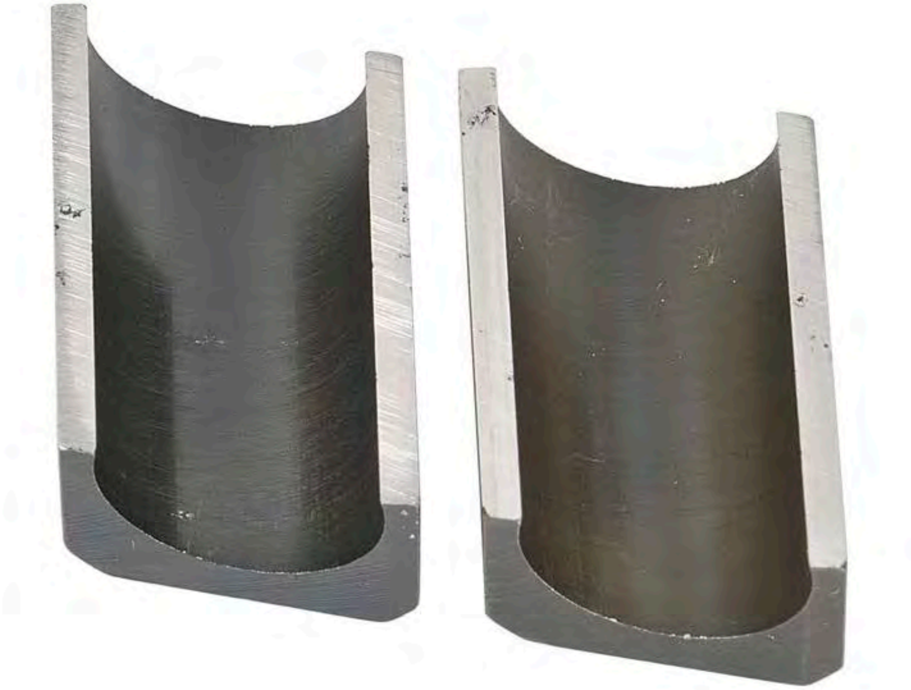


SN15438885 Transfer Pump Blades, After

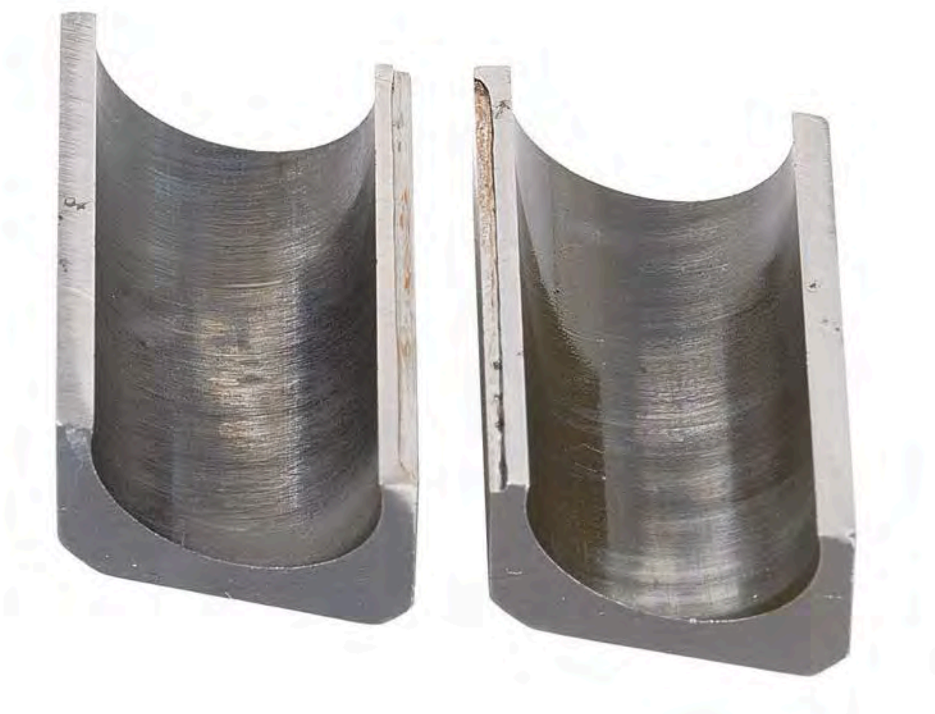


SN15438885 Transfer Pump Blades (Profile), Before

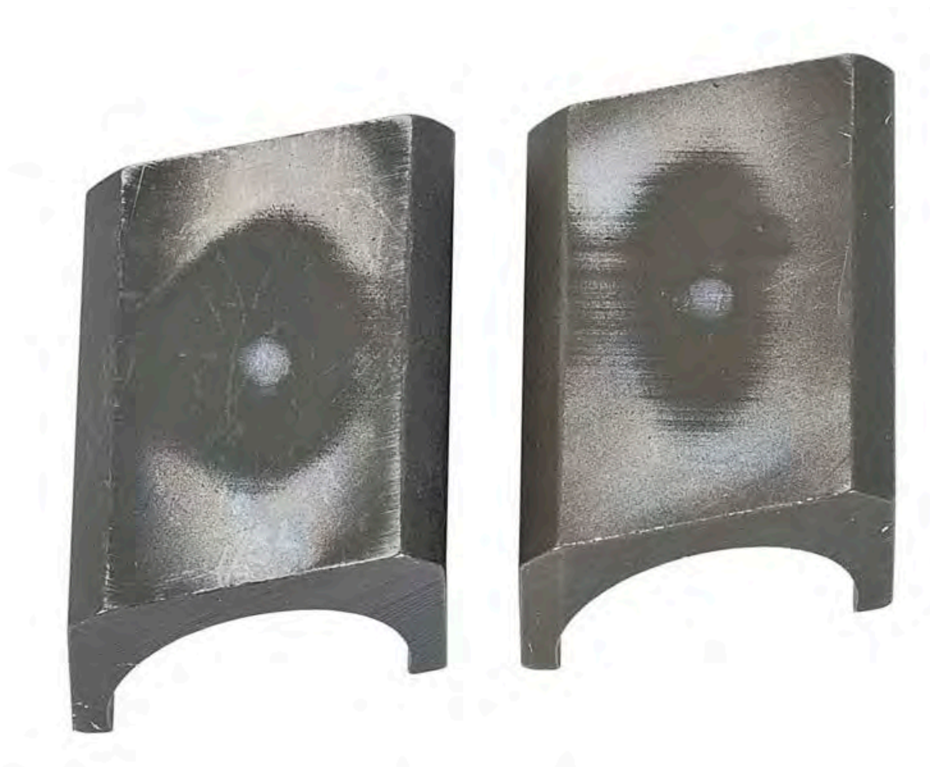
SN15438885 Transfer Pump Blades (Profile), After



SN15438885 Shoes (Front), Before



SN15438885 Shoes (Front), After



SN15438885 Shoes (Back), Before

SN15438885 Shoes (Back), After

SN15438885 Rollers, Before

SN15438885 Rollers, After

SN15438885 Piston Plungers, Before

SN15438885 Piston Plungers, After

SN15438885 Thrust Washer, Before

SN15438885 Thrust Washer, After

SN15438885 Governor Weight, Before

SN15438885 Governor Weight, After

SN15438885 Cam Ring, Before

SN15438885 Cam Ring, After

SN15438885 Eccentric Ring, Before

SN15438885 Eccentric Ring, After

SN15438885 Rotor (Front), Before

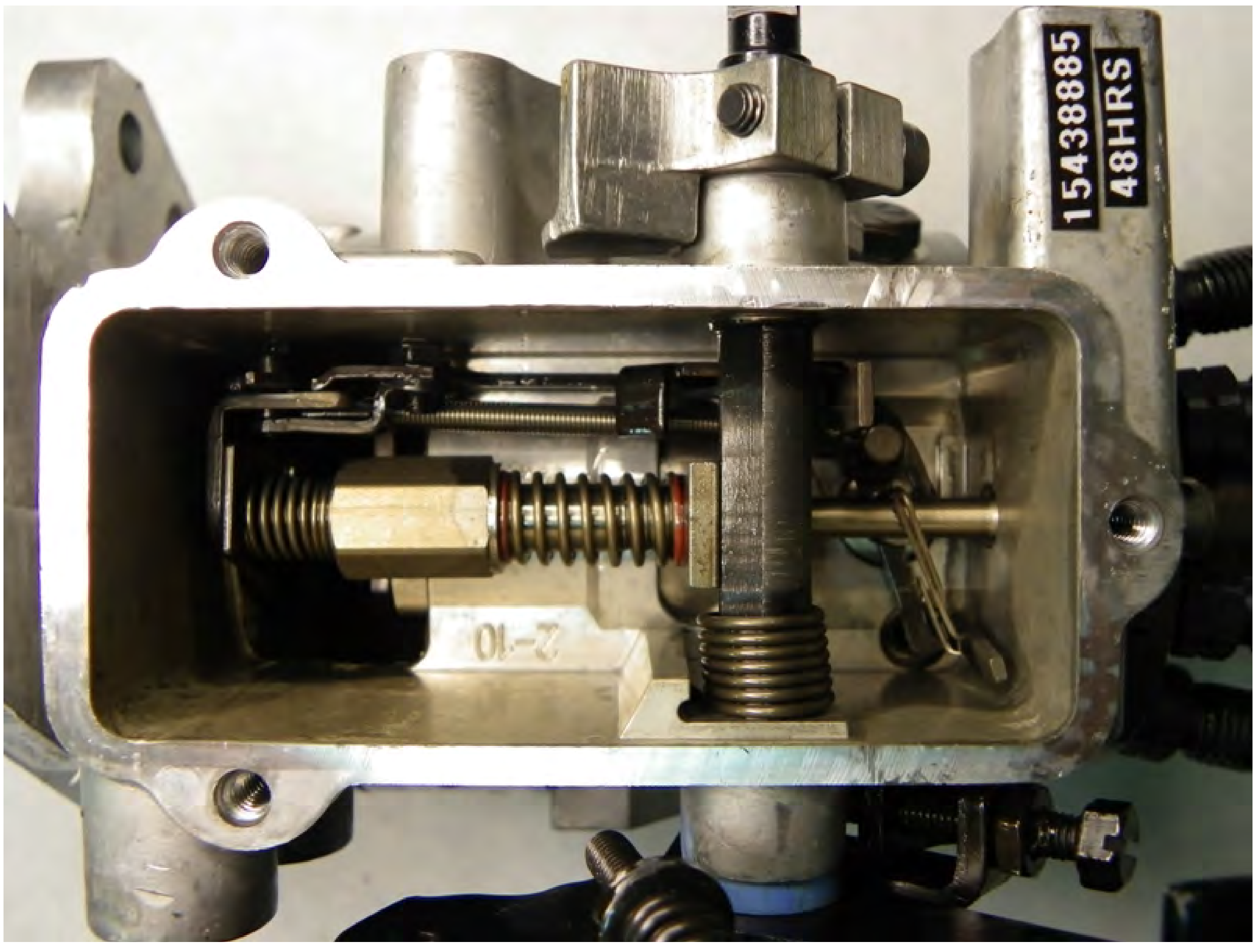
SN15438885 Rotor (Front), After

SN15438885 Rotor (Back), Before

SN15438885 Rotor (Back), After

SN15438885 Drive Tang, Before

SN15438885 Drive Tang, After



SN15438885 Governor Assembly

APPENDIX P

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: FT-SPK with 22.5-mg/L DCI-4A
Test Number: C4T16-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: FT-SPK with 22.5-mg/L DCI-4A

Test Fuel ID: AL27892

Test Temperature: 40°C (105°F)

Test Number: C4T16-40-1000

Start of Test Date: December 05, 2011

End of Test Date: February 15, 2011

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure P-1.

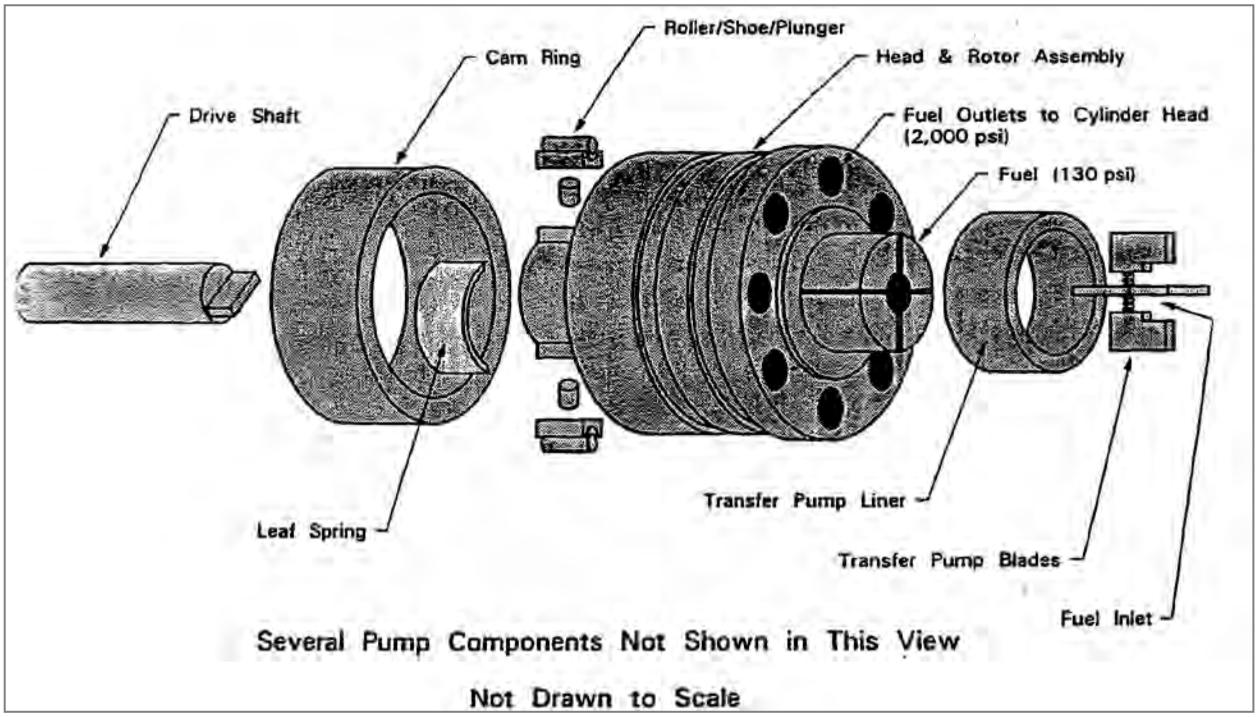


Figure P-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table P-1.

Table P-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table P-2.

Table P-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1701	2.74
FLO_R	Injected Flow-rate [mL/min]	746	17.06
FUELIN_P	Fuel Inlet Pressure [psig]	2.8	0.25
TRNS_P_R	Transfer Pump Pressure [psig]	74	0.86
HSG_P_R	Pump Housing Pressure [psig]	11.3	0.87
RTRN_T_R	Fuel Return Temperature [°C]	47.3	1.3
FUEL_T	Fuel Tank Temperature [°C]	38.2	93.1
FUELIN_T	Fuel Inlet Temperature [°C]	40	0.31

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure P-2 through Figure P-4.

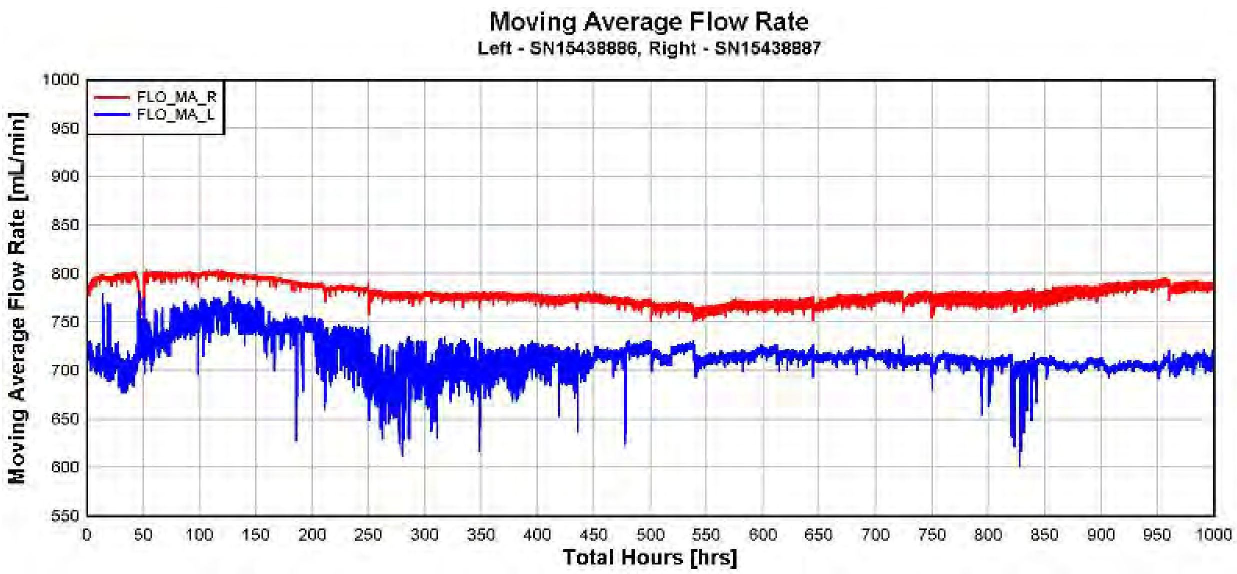


Figure P-2. Pump Flow, Moving Average

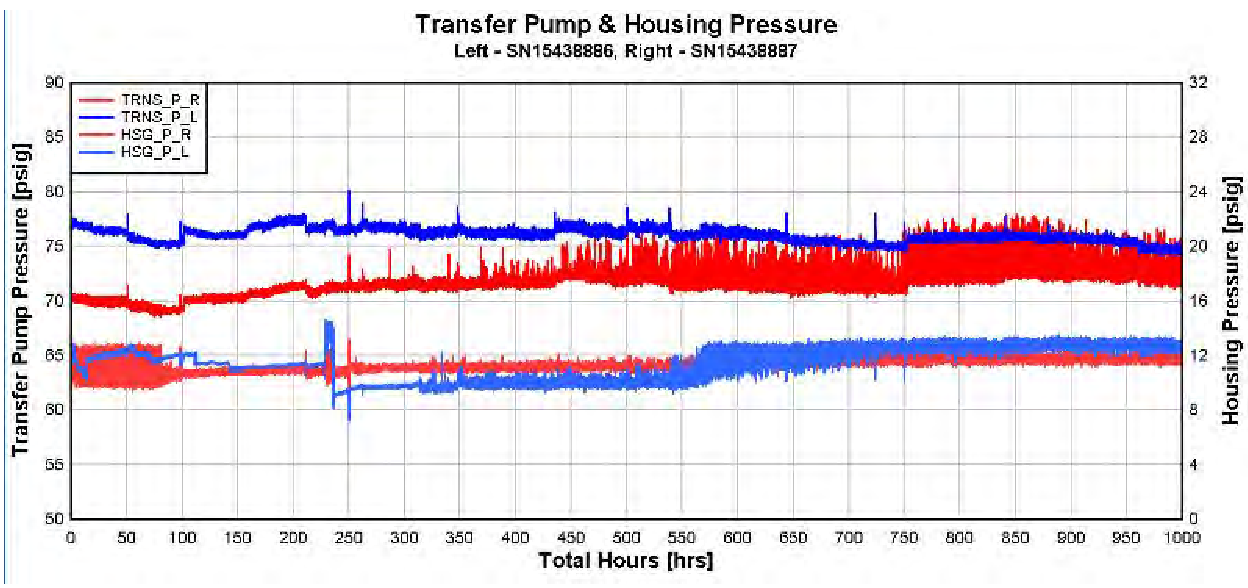


Figure P-3. Transfer Pump & Housing Pressure

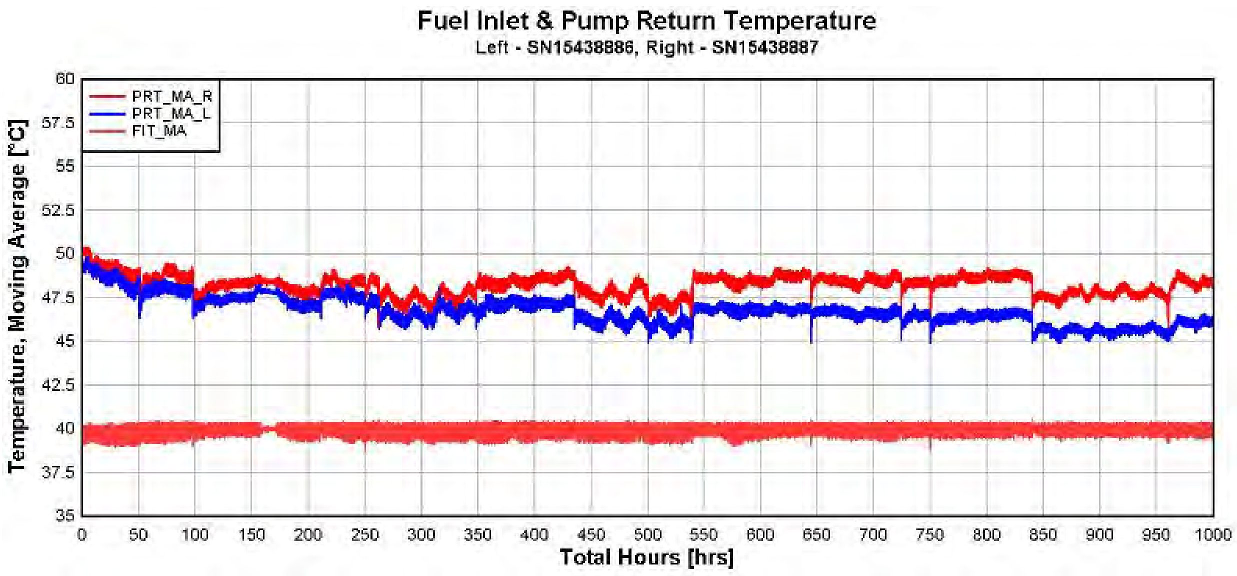


Figure P-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table P-3. (Note – Calibration data to be used as reference only).

Table P-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 16			Test Duration : 1000-hrs.		
Test Fuel :	FT-SPK w/22.5-mg/L DCI-4A @ 105°F			SN : 15438886			SN : 15438887		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	62 psi	psi	62 psi	60 psi	2 psi
	Return Fuel	225 cc	375 cc	360 cc	**388 cc**	-28 cc	296 cc	310 cc	-14 cc
350	Low Idle	12 cc	16 cc	15 cc	15 cc	1 cc	14 cc	**8 cc**	6 cc
	Housing psi.	8 psi	12 psi	8.0 psi	10.5 psi	-2.5 psi	10.0 psi	11.0 psi	-1.0 psi
	Advance	3.50°		3.75°	**3.12°**	.63°	5.32°	5.41°	-.09°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	67.0 cc	.0 cc	67.0 cc	**66.0 cc**	1.0 cc
1600	WOT Fuel delivery	60 cc		64 cc	60 cc	4 cc	61 cc	61 cc	cc
	WOT Advance	2.50°	3.50°	3.07°	2.59°	.48°	3.00°	**3.73°**	-.73°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	22.0 cc	.0 cc	23.0 cc	22.0 cc	1.0 cc
	Face Cam Advance	5.25°	7.25°	5.80°	5.36°	.44°	6.33°	6.68°	-.35°
	Low Idle	11.0°	12.0°	11.0°	**10.9°**	.1°	**11.0°**	**11.0°**	.0°
1825	Fuel Delivery	33 cc		37 cc	51 cc	-14 cc	38 cc	51 cc	-13 cc
1950	High Idle		15 cc	2 cc	2 cc	cc	2 cc	2 cc	cc
	Transfer pump psi.		125 psi	108 psi	106 psi	2 psi	101 psi	102 psi	-1 psi
200	WOT Fuel Delivery	58 cc		59 cc	61 cc	-2 cc	59 cc	59 cc	0 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		47 cc	47 cc	cc	48 cc	48 cc	cc
	Transfer pump psi.	16 psi		25 psi	25 psi	0 psi	25 psi	27 psi	-2 psi
	Housing psi.	.0 psi	12 psi	9.0 psi	10 psi	-1 psi	10 psi	11 psi	-1 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	.00°	.00°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table P-4 and Table P-5.

Table P-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438886	Test Number: 16	
Fuel Description : FT-SPK w/22.5-mg/L DCI-4A @ 105°F				
	Date:	1/0/1900	5/15/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000.-hrs.***	***Change***
Measurement 1	Mass (g)	3.2842	3.2800	-0.0042
Measurement 2		3.2840	3.2799	-0.0041
Measurement 3		3.2839	3.2799	-0.0040
Measurement 4		3.2840	3.2800	-0.0040
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2661	3.2635	-0.0026
Measurement 2		3.2660	3.2635	-0.0025
Measurement 3		3.2660	3.2634	-0.0026
Measurement 4		3.2659	3.2633	-0.0026
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2421	3.2359	-0.0062
Measurement 2		3.2421	3.2358	-0.0063
Measurement 3		3.2421	3.2359	-0.0062
Measurement 4		3.2421	3.2359	-0.0062
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2661	3.2599	-0.0062
Measurement 2		3.2660	3.2600	-0.0060
Measurement 3		3.2660	3.2601	-0.0059
Measurement 4		3.2660	3.2601	-0.0059
Average Measurements		***0-hrs.***	***1000.-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2840	3.2800	-0.0041
Transfer Pump Blade 2		3.2660	3.2634	-0.0026
Transfer Pump Blade 3		3.2421	3.2359	-0.0062
Transfer Pump Blade 4		3.2660	3.2600	-0.0060
	Roller to Roller (in)	1.9760	1.9763	0.0003
	Eccentricity (in.)	0.0050	0.0150	0.0100
	Drive Backlash (In)	0.0050	0.0075	0.0025

Table P-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438887	Test Number: 16	
Fuel Description : FT-SPK w/22.5-mg/L DCI-4A @ 105°F				

	Date:	1/0/1900	5/15/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2540	3.2489	-0.0051
Measurement 2		3.2542	3.2490	-0.0052
Measurement 3		3.2542	3.2489	-0.0053
Measurement 4		3.2543	3.2489	-0.0054
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2853	3.2839	-0.0014
Measurement 2		3.2854	3.2839	-0.0015
Measurement 3		3.2852	3.2840	-0.0012
Measurement 4		3.2852	3.2841	-0.0011
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2494	3.2385	-0.0109
Measurement 2		3.2493	3.2387	-0.0106
Measurement 3		3.2493	3.2386	-0.0107
Measurement 4		3.2493	3.2356	-0.0137
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2121	3.2089	-0.0032
Measurement 2		3.2122	3.2089	-0.0033
Measurement 3		3.2122	3.2089	-0.0033
Measurement 4		3.2121	3.2089	-0.0032
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2542	3.2489	-0.0053
Transfer Pump Blade 2		3.2853	3.2840	-0.0013
Transfer Pump Blade 3		3.2493	3.2379	-0.0115
Transfer Pump Blade 4		3.2122	3.2089	-0.0033
	Roller to Roller (in)	1.9760	1.9760	0.0000
	Eccentricity (in.)	0.0050	0.0080	0.0030
	Drive Backlash (In)	0.0050	0.0090	0.0040

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table P-6.

Table P-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
16	15438886	FT-SPK w/22.5-mg/L DCI-4A @ 105°F	16-1	2100	1625	Pass	Fail	Pass	Pass	Pass	Pass
			16-2	2100	1625	Pass	Fail	Pass	Pass	Pass	Pass
			16-3	2150	1525	Pass	Fail	Pass	Pass	Pass	Pass
			16-4	2100	1500	Pass	Fail	Pass	Pass	Pass	Pass
			16-5	2100	1650	Pass	Fail	Pass	Pass	Pass	Pass
			16-6	2075	1675	Pass	Fail	Pass	Pass	Pass	Pass
			16-7	2175	1700	Pass	Fail	Pass	Pass	Pass	Pass
			16-8	2100	1600	Pass	Fail	Pass	Pass	Pass	Pass
16	15438887	FT-SPK w/22.5-mg/L DCI-4A @ 105°F	16-11	2175	1675	Pass	Pass	Pass	Pass	Pass	Pass
			16-12	2125	1575	Pass	Fail	Pass	Pass	Pass	Pass
			16-13	2150	1600	Pass	Fail	Pass	Pass	Pass	Pass
			16-14	2150	1550	Pass	Fail	Pass	Pass	Pass	Pass
			16-15	2075	1525	Pass	Fail	Pass	Pass	Pass	Pass
			16-16	2100	1625	Pass	Fail	Pass	Pass	Pass	Pass
			16-17	2125	1675	Pass	Pass	Pass	Pass	Pass	Pass
			16-18	2125	1650	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 3 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table P-7 and Table P-8.

Table P-7. Stanadyne Left Pump Parts Evaluation

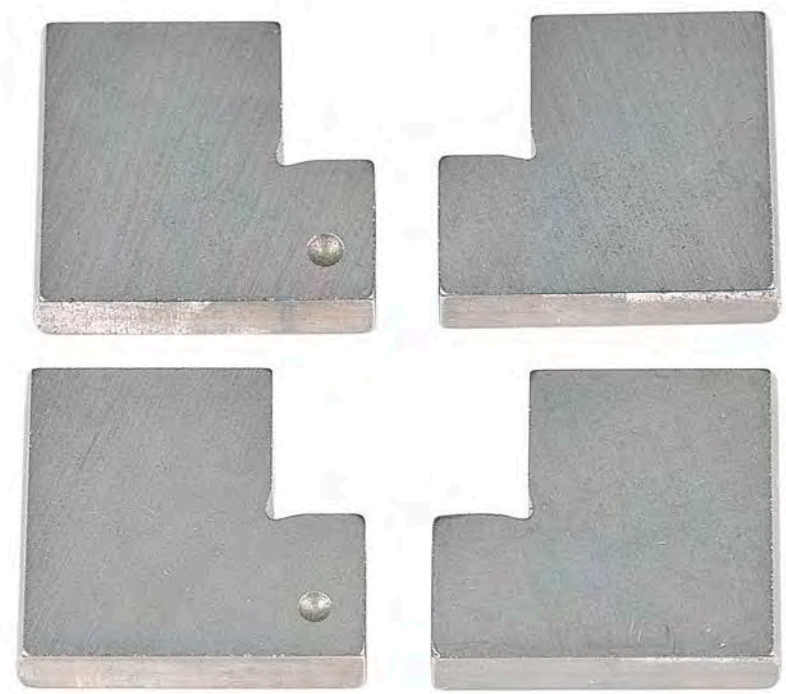
Pump Type : DB2831-5079		SN: 15438886
Test Condition : FT-SPK w/22.5-mg/L DCI-4A @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing wear	1
LINER	90% Wear	3
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Polishing wear	1.5
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Polishing wear	2
SHOES	Dimple, light waer from leaf spring contact	2
ROLLERS	Discolored	1.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Polishing wear	1
THRUST WASHER	Groove from weight contact	2.5
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2
LINK HOOK	Dimple from governor rod	2
METERING VAVLE	Polishing wear	1.5
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scorring wear	3.5
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.761

Table P-8. Stanadyne Right Pump Parts Evaluation

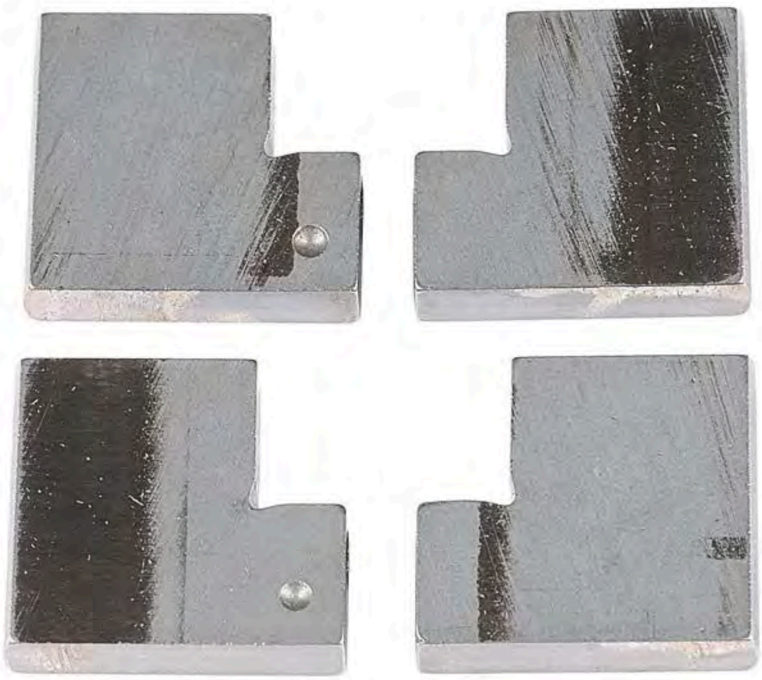
Pump Type : DB2831-5079	SN: 15438887
Test Condition : FT-SPK w/22.5-mg/L DCI-4A @ 105°F	Pump Duration : 1000.-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing wear	1
LINER	90% Wear	3
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	1.5
REGULATOR PISTON	Polishing wear	1.5
ROTOR	Wear at distributor ports	2.5
ROTOR RETAINERS	Wear from rotor contact	2.5
DELIVERY VALVE	Polishing wear	1.5
PLUNGERS	Polishing wear and light scratces	2.5
SHOES	Dimple, light waer from leaf spring contact	2
ROLLERS	Discolored and light scorring	2.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Polishing wear	1
THRUST WASHER	Groove from weight contact	2.5
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2
LINK HOOK	Dimple from governor rod	2
METERING VAVLE	Polishing wear	1.5
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scorring wear	3
HOUSING	Normal	1
	AVERAGE DEMERIT RATINGS	1.826

PHOTOGRAPHS FOR LEFT PUMP



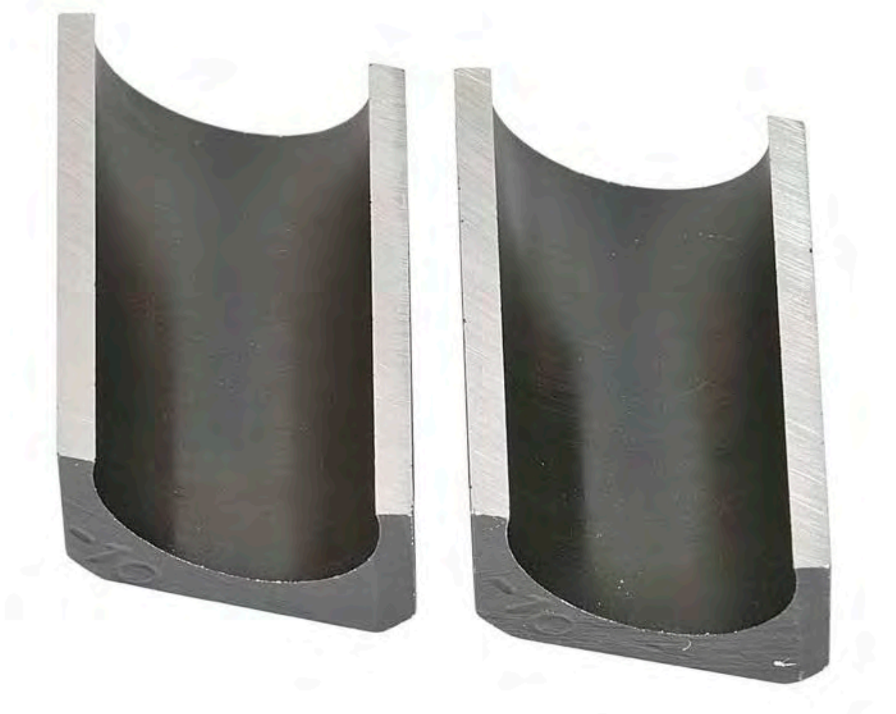
SN15438886 Transfer Pump Blades (Side), Before



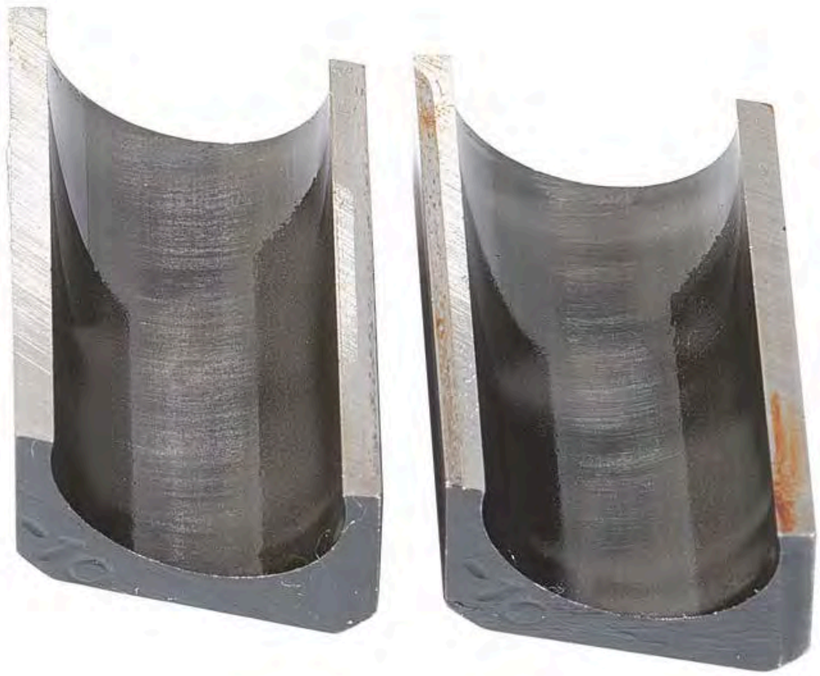
SN15438886 Transfer Pump Blades (Side), After

SN15438886 Transfer Pump Blades (Profile), Before

SN15438886 Transfer Pump Blades (Profile), After



SN15438886 Shoes (Front), Before



SN15438886 Shoes (Front), After

SN15438886 Shoes (Back), Before

SN15438886 Shoes (Back), After

SN15438886 Rollers, Before

SN15438886 Rollers, After

SN15438886 Piston Plungers, Before

SN15438886 Piston Plungers, After

SN15438886 Thrust Washer, Before

SN15438886 Thrust Washer, After

SN15438886 Governor Weight, Before

SN15438886 Governor Weight, After

SN15438886 Cam Ring, Before

SN15438886 Cam Ring, After

SN15438886 Eccentric Ring, Before

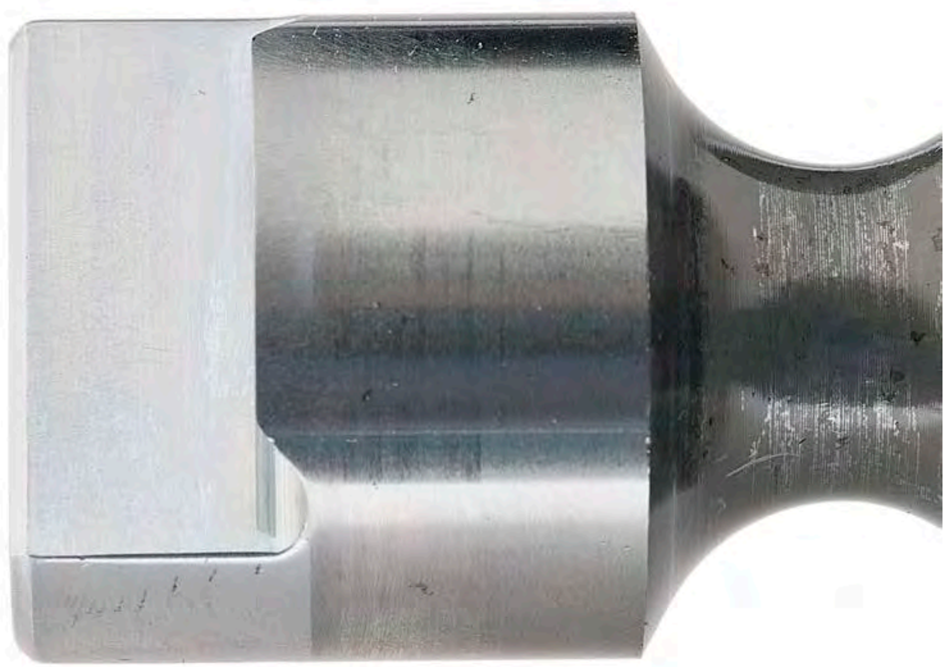
SN15438886 Eccentric Ring, After

SN15438886 Rotor (Front), Before

SN15438886 Rotor (Front), After

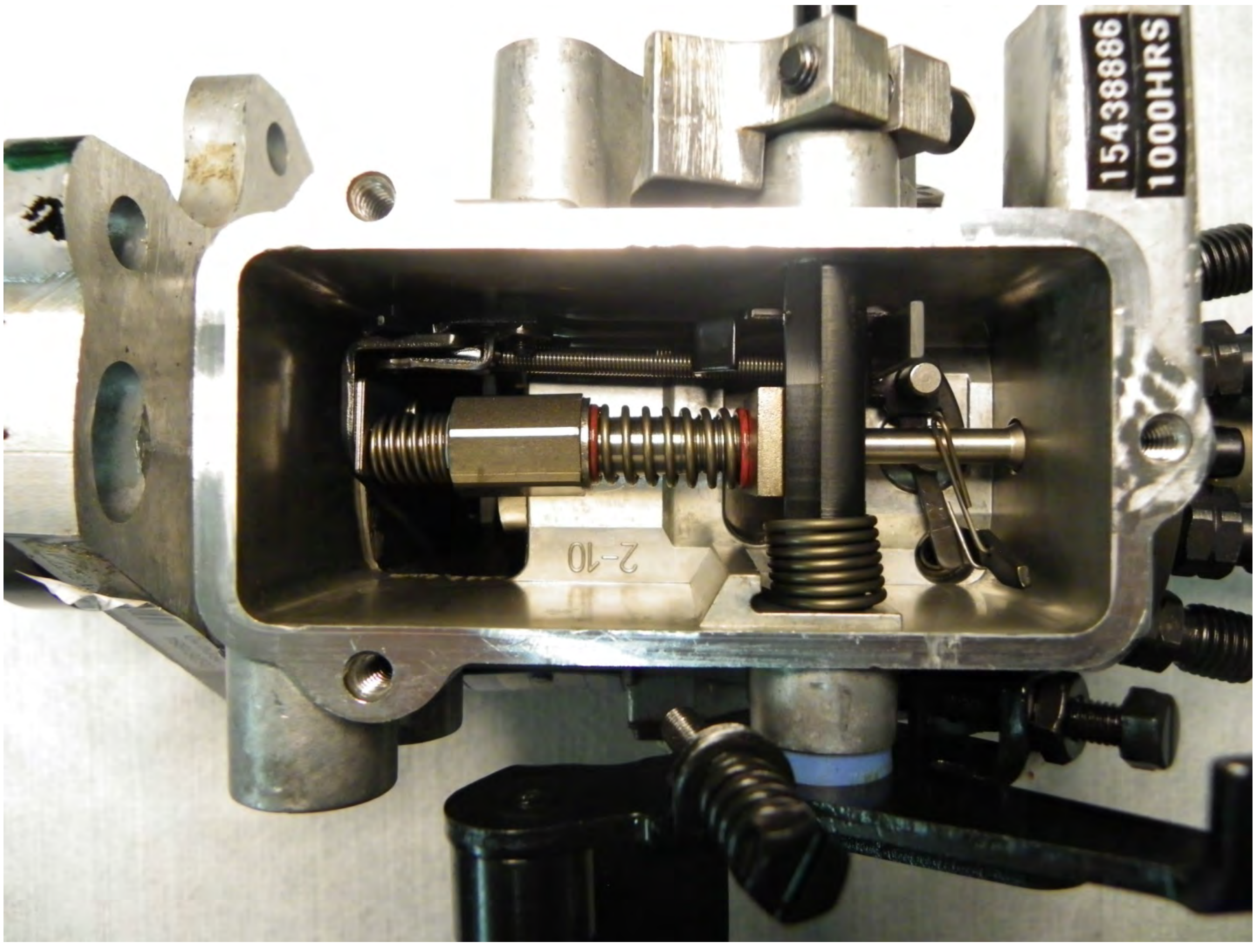
SN15438886 Rotor (Back), Before

SN15438886 Rotor (Back), After



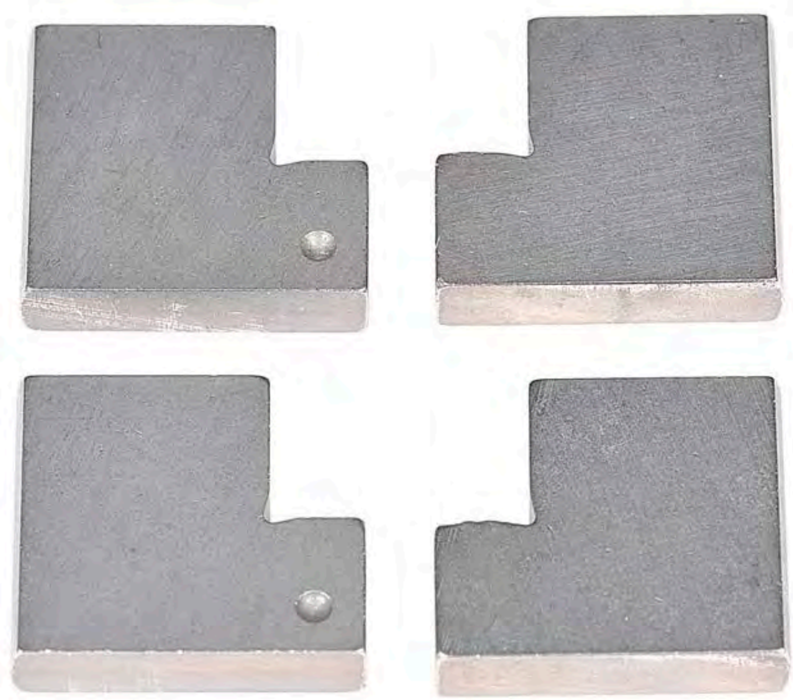
SN15438886 Drive Tang, Before

SN15438886 Drive Tang, After

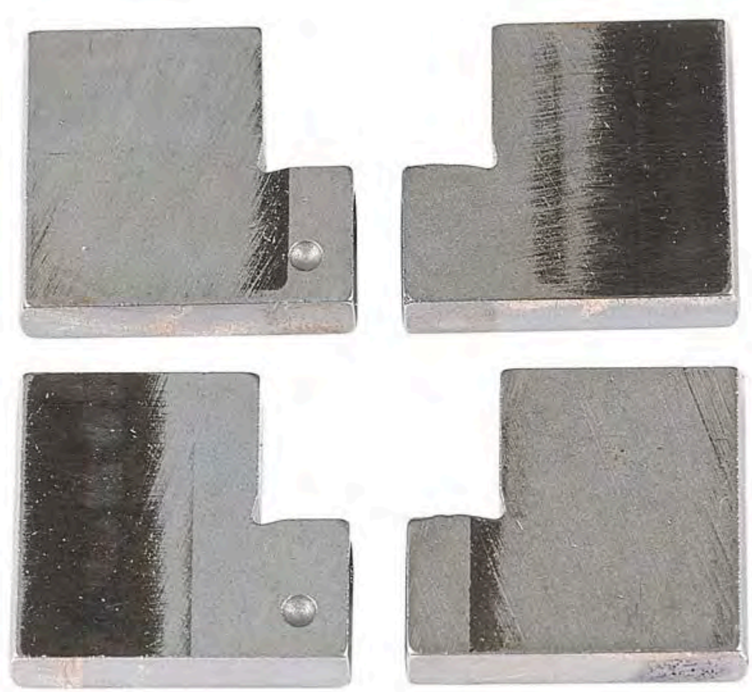


SN15438886 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



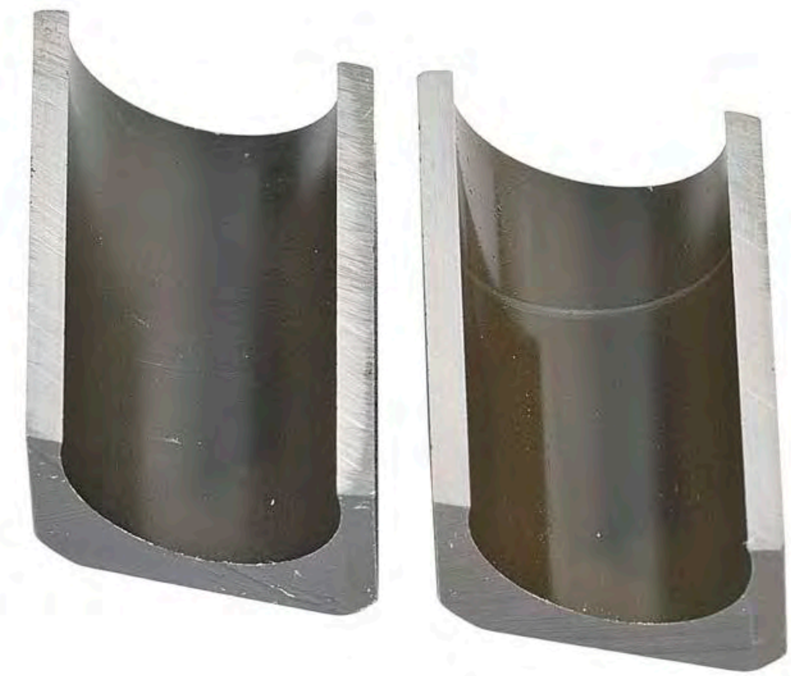
SN15438887 Transfer Pump Blades, Before



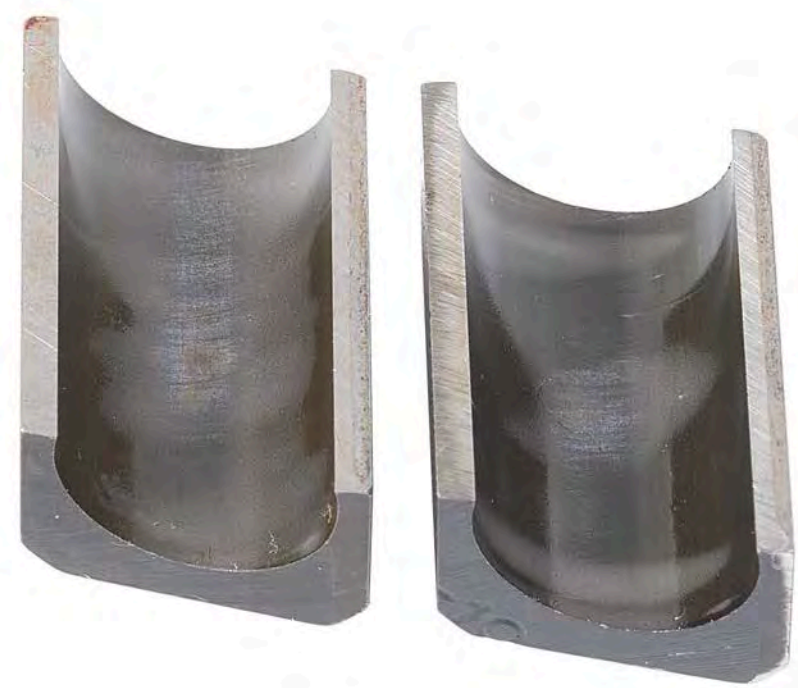
SN15438887 Transfer Pump Blades, After

SN15438887 Transfer Pump Blades (Profile), Before

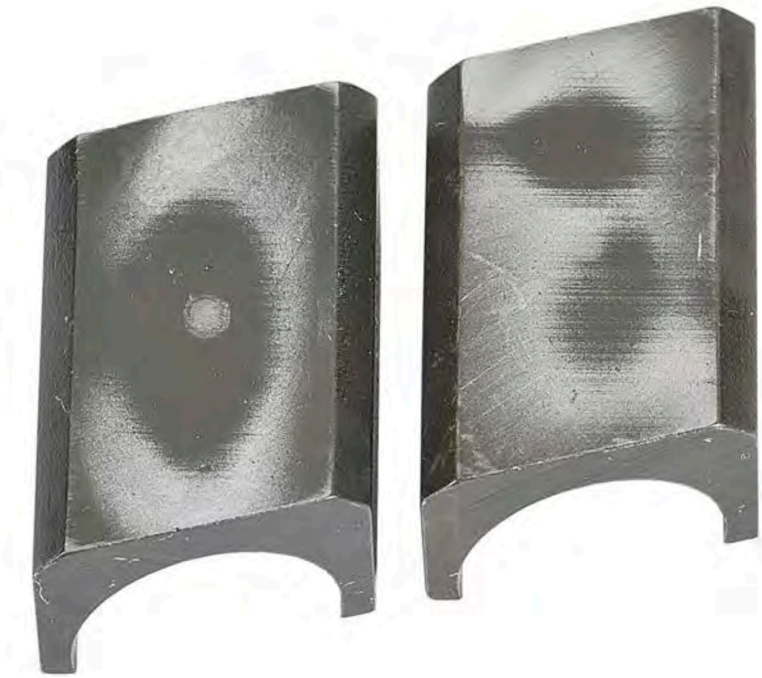
SN15438887 Transfer Pump Blades (Profile), After



SN15438887 Shoes (Front), Before



SN15438887 Shoes (Front), After



SN15438887 Shoes (Back), Before

SN15438887 Shoes (Back), After

SN15438887 Rollers, Before

SN15438887 Rollers, After

SN15438887 Piston Plungers, Before

SN15438887 Piston Plungers, After

SN15438887 Thrust Washer, Before

SN15438887 Thrust Washer, After

SN15438887 Governor Weight, Before

SN15438887 Governor Weight, After

SN15438887 Cam Ring, Before

SN15438887 Cam Ring, After

SN15438887 Eccentric Ring, Before

SN15438887 Eccentric Ring, After

SN15438887 Rotor (Front), Before

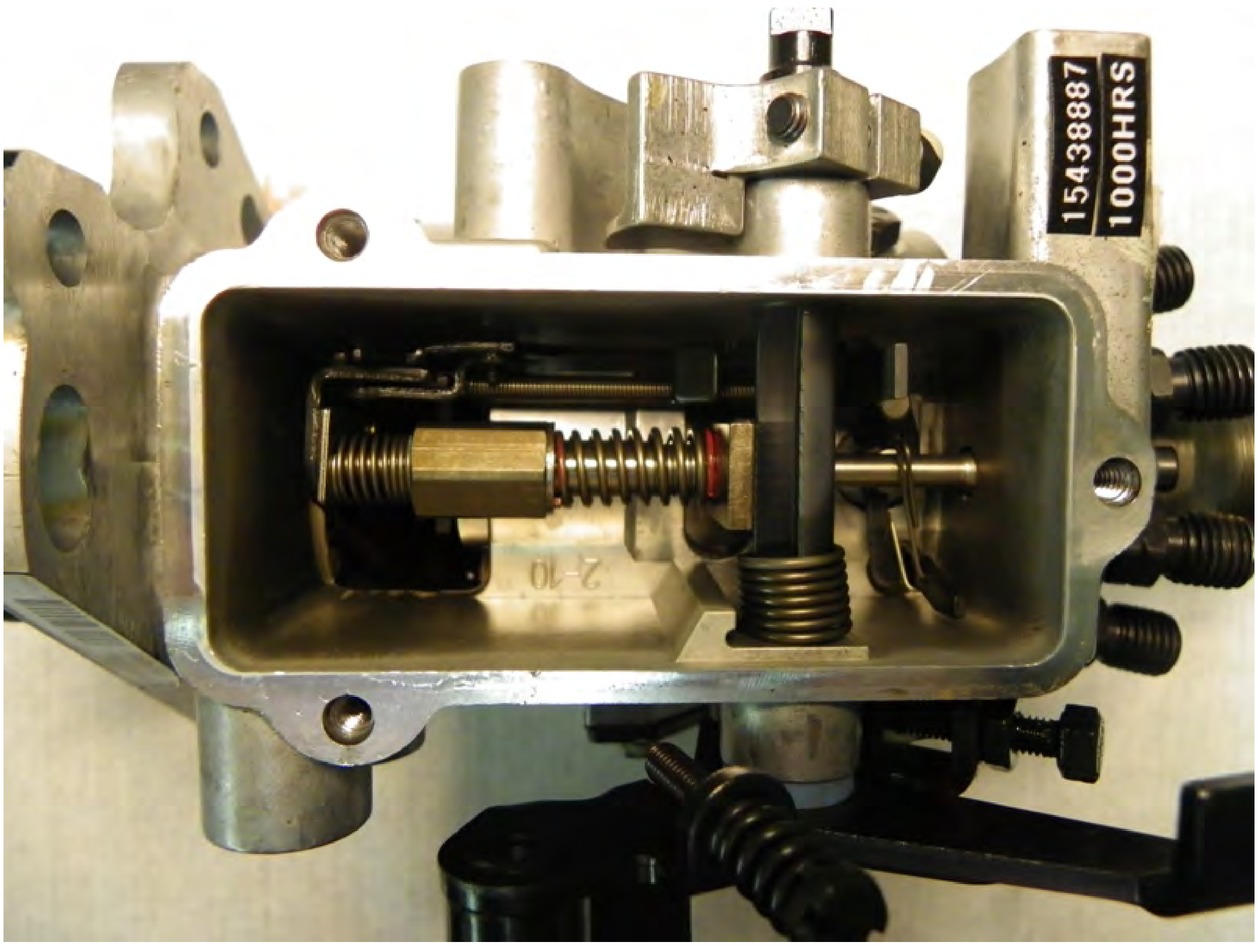
SN15438887 Rotor (Front), After

SN15438887 Rotor (Back), Before

SN15438887 Rotor (Back), After

SN15438887 Drive Tang, Before

SN15438887 Drive Tang, After



SN15438887 Governor Assembly

APPENDIX Q

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: FT-SPK with 22.5-mg/L DCI-4A
Test Number: C3T17-57-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: FT-SPK with 22.5-mg/L DCI-4A

Test Fuel ID: AL-27892

Test Temperature: 57°C (135°F)

Test Number: C3T17-57-1000

Start of Test Date: January 10, 2012

End of Test Date: March 10, 2012

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure Q-1.

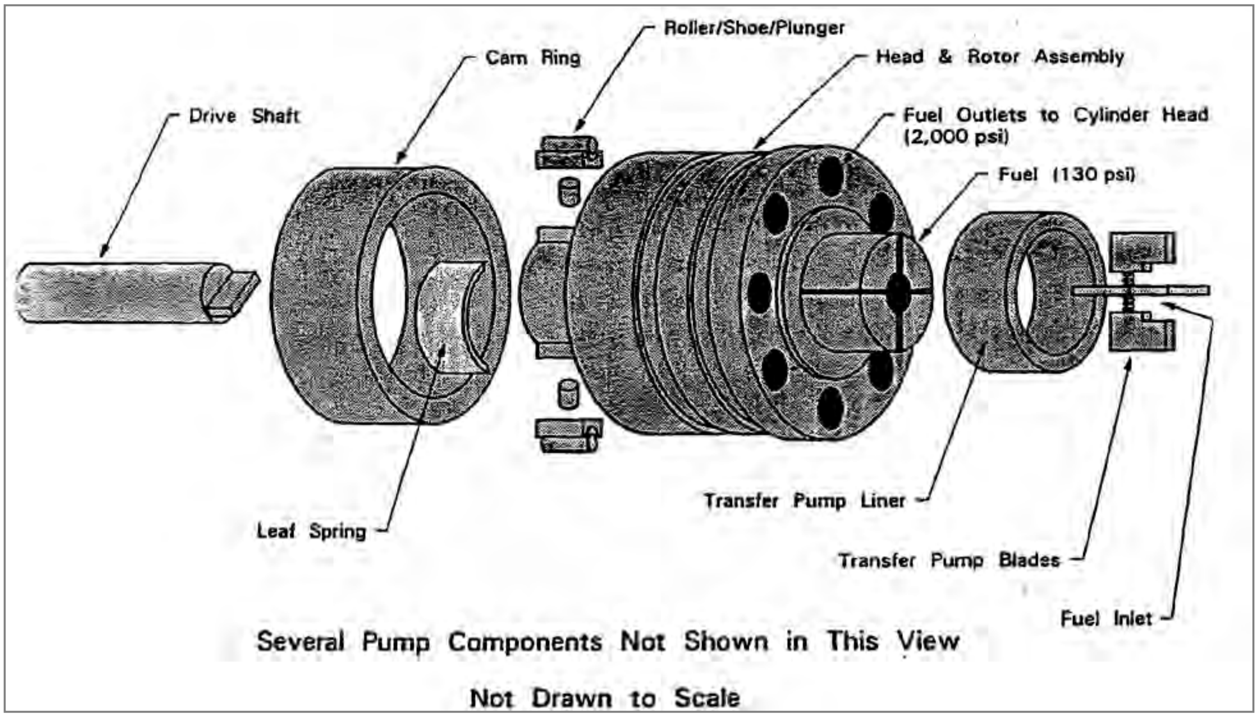


Figure Q-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table Q-1.

Table Q-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	57 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table Q-2.

Table Q-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.06
FLO_R	Injected Flow-rate [mL/min]	724.8	12.49
FUELIN_P	Fuel Inlet Pressure [psig]	2.7	0.16
TRNS_P_R	Transfer Pump Pressure [psig]	71.7	0.82
HSG_P_R	Pump Housing Pressure [psig]	11.6	0.22
RTRN_T_R	Fuel Return Temperature [°C]	63.8	0.96
FUEL_T	Fuel Tank Temperature [°C]	29.8	3.35
FUELIN_T	Fuel Inlet Temperature [°C]	57	0.68

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure Q-2 through Figure Q-4.

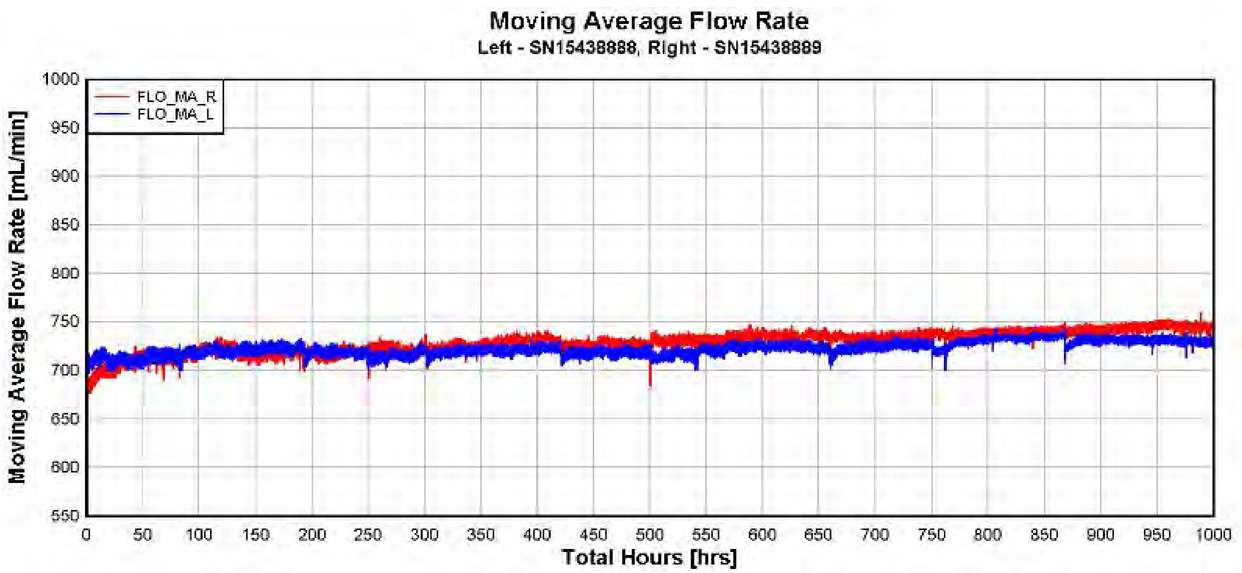


Figure Q-2. Pump Flow, Moving Average

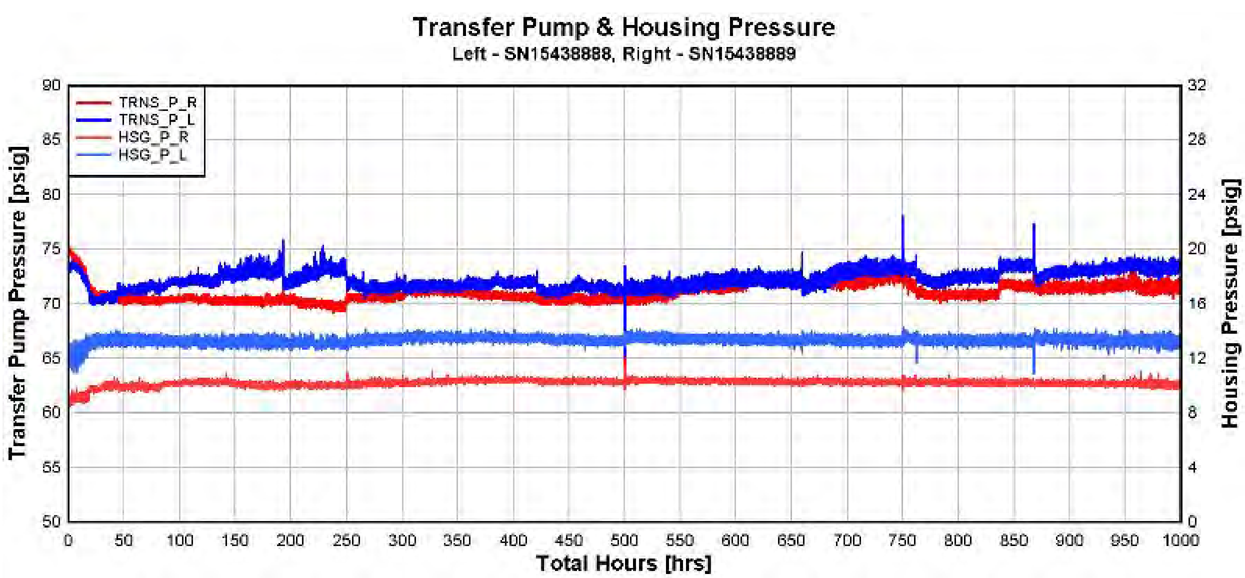


Figure Q-3. Transfer Pump & Housing Pressure

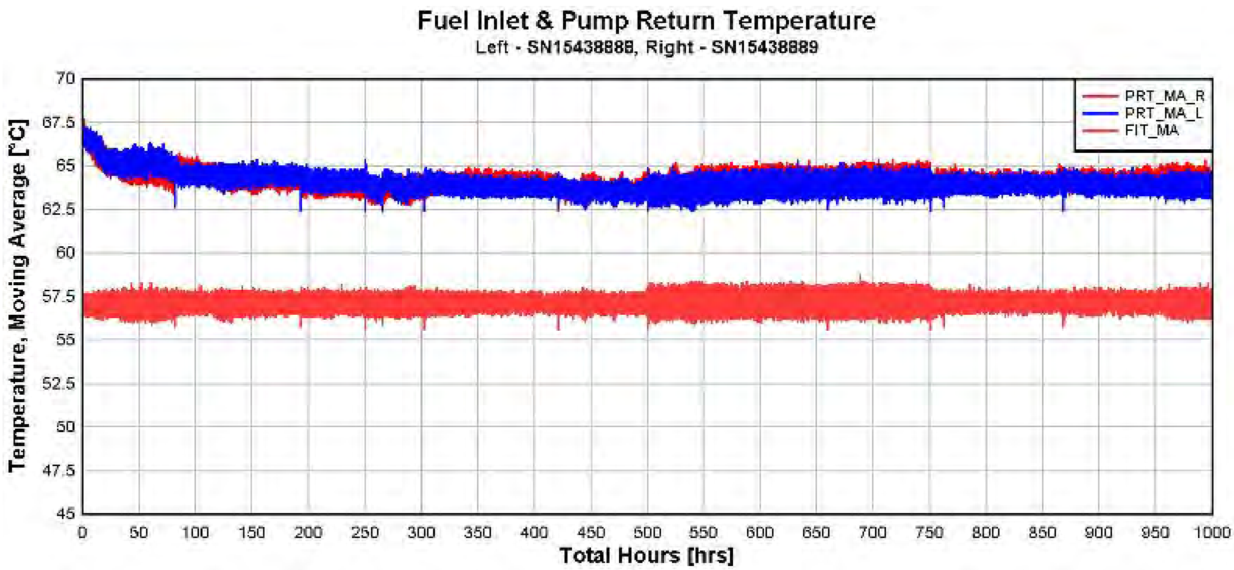


Figure Q-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table Q-3. (Note – Calibration data to be used as reference only).

Table Q-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 17			Test Duration : 1000-hrs.		
Test Fuel :	FT-SPK w/22.5-mg/L DCI-4A @ 135°F			SN : 15438888			SN : 15438889		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	61 psi	1 psi	61 psi	60 psi	1 psi
	Return Fuel	225 cc	375 cc	340 cc	326 cc	14 cc	322 cc	317 cc	5 cc
350	Low Idle	12 cc	16 cc	16 cc	**6 cc**	10 cc	15 cc	**4 cc**	11 cc
	Housing psi.	8 psi	12 psi	11.0 psi	10.0 psi	1.0 psi	10.0 psi	9.0 psi	1.0 psi
	Advance	3.50°		5.00°	4.90°	.10°	5.25°	4.04°	1.21°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	**65.0 cc**	2.0 cc	67.0 cc	67.0 cc	.0 cc
1600	WOT Fuel delivery	60 cc		63 cc	61 cc	2 cc	62 cc	64 cc	-2 cc
	WOT Advance	2.50°	3.50°	3.03°	3.45°	-.42°	3.04°	2.82°	.22°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	23.0 cc	22.0 cc	1.0 cc
	Face Cam Advance	5.25°	7.25°	6.41°	6.58°	-.17°	6.42°	5.95°	.47°
	Low Idle	11.0°	12.0°	**11.0°**	11.1°	-.1°	11.1°	**10.7°**	.4°
1825	Fuel Delivery	33 cc		38 cc	51 cc	-13 cc	39 cc	60 cc	-21 cc
1950	High Idle		15 cc	3 cc	2 cc	1 cc	2 cc	1 cc	1 cc
	Transfer pump psi.		125 psi	110 psi	110 psi	0 psi	108 psi	105 psi	3 psi
200	WOT Fuel Delivery	58 cc		59 cc	60 cc	-1 cc	60 cc	62 cc	-2 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		50 cc	49 cc	1 cc	48 cc	49 cc	-1 cc
	Transfer pump psi.	16 psi		25 psi	28 psi	-3 psi	26 psi	27 psi	-1 psi
	Housing psi.	.0 psi	12 psi	9.0 psi	9 psi	0 psi	10 psi	9 psi	2 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :
Pump SN:15438888-Orange fluorocarbon seal torn
Pump SN:15438889-Orange fluorocarbon seal torn
Brown stain in both pumps.

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table Q-4 and Table Q-5.

Table Q-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438888	Test Number: 17	
Fuel Description : FT-SPK w/22.5-mg/L DCI-4A @ 135°F				
	Date:	1/0/1900	5/23/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000.-hrs.***	***Change***
Measurement 1	Mass (g)	3.2814	3.2664	-0.0150
Measurement 2		3.2813	3.2665	-0.0148
Measurement 3		3.2813	3.2664	-0.0149
Measurement 4		3.2813	3.2664	-0.0149
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2832	3.2710	-0.0122
Measurement 2		3.2832	3.2711	-0.0121
Measurement 3		3.2831	3.2712	-0.0119
Measurement 4		3.2832	3.2711	-0.0121
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2615	3.2436	-0.0179
Measurement 2		3.2615	3.2437	-0.0178
Measurement 3		3.2615	3.2435	-0.0180
Measurement 4		3.2615	3.2436	-0.0179
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2575	3.2365	-0.0210
Measurement 2		3.2575	3.2364	-0.0211
Measurement 3		3.2574	3.2365	-0.0209
Measurement 4		3.2574	3.2366	-0.0208
Average Measurements		***0-hrs.***	***1000.-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2813	3.2664	-0.0149
Transfer Pump Blade 2		3.2832	3.2711	-0.0121
Transfer Pump Blade 3		3.2615	3.2436	-0.0179
Transfer Pump Blade 4		3.2575	3.2365	-0.0209
	Roller to Roller (in)	1.9763	1.9757	-0.0006
	Eccentricity (in.)	0.0100	0.0120	0.0020
	Drive Backlash (In)	0.0050	0.0080	0.0030

Table Q-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)	SN: 15438889	Test Number: 17
Fuel Description : FT-SPK w/22.5-mg/L DCI-4A @ 135°F		

	Date:	1/0/1900	5/23/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2329	3.2185	-0.0144
Measurement 2		3.2329	3.2188	-0.0141
Measurement 3		3.2330	3.2187	-0.0143
Measurement 4		3.2329	3.2187	-0.0142
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2304	3.2102	-0.0202
Measurement 2		3.2305	3.2103	-0.0202
Measurement 3		3.2304	3.2103	-0.0201
Measurement 4		3.2304	3.2104	-0.0200
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2565	3.2358	-0.0207
Measurement 2		3.2564	3.2358	-0.0206
Measurement 3		3.2563	3.2359	-0.0204
Measurement 4		3.2563	3.2359	-0.0204
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2932	3.2811	-0.0121
Measurement 2		3.2931	3.2810	-0.0121
Measurement 3		3.2931	3.2810	-0.0121
Measurement 4		3.2932	3.2809	-0.0123
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2329	3.2187	-0.0142
Transfer Pump Blade 2		3.2304	3.2103	-0.0201
Transfer Pump Blade 3		3.2564	3.2359	-0.0205
Transfer Pump Blade 4		3.2932	3.2810	-0.0122
	Roller to Roller (in)	1.9763	1.9761	-0.0002
	Eccentricity (in.)	0.0100	0.0070	-0.0030
	Drive Backlash (In)	0.0000	0.0070	0.0070

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table Q-6.

Table Q-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
17	15438888	FT-SPK w/22.5-mg/L DCI-4A @ 135°F	17-1	2125	1525	Pass	Fail	Pass	Pass	Pass	Pass
			17-2	2150	1675	Pass	Fail	Pass	Pass	Pass	Pass
			17-3	2100	1675	Pass	Fail	Pass	Pass	Pass	Pass
			17-4	2125	1675	Pass	Fail	Pass	Pass	Pass	Pass
			17-5	2175	1775	Pass	Pass	Pass	Pass	Pass	Pass
			17-6	2200	1800	Pass	Pass	Pass	Pass	Pass	Pass
			17-7	2175	1800	Pass	Pass	Pass	Pass	Pass	Pass
			17-8	2200	1725	Pass	Fail	Pass	Pass	Pass	Pass
17	15438889	FT-SPK w/22.5-mg/L DCI-4A @ 135°F	17-11	2150	1800	Pass	Pass	Pass	Pass	Pass	Pass
			17-12	2175	1700	Pass	Pass	Pass	Pass	Pass	Pass
			17-13	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			17-14	2175	1725	Pass	Pass	Pass	Pass	Pass	Pass
			17-15	2125	1750	Pass	Pass	Pass	Pass	Pass	Pass
			17-16	2175	1800	Pass	Pass	Pass	Pass	Pass	Pass
			17-17	2100	1725	Pass	Pass	Pass	Pass	Pass	Pass
			17-18	2125	1725	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 11 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table Q-7 and Table Q-8.

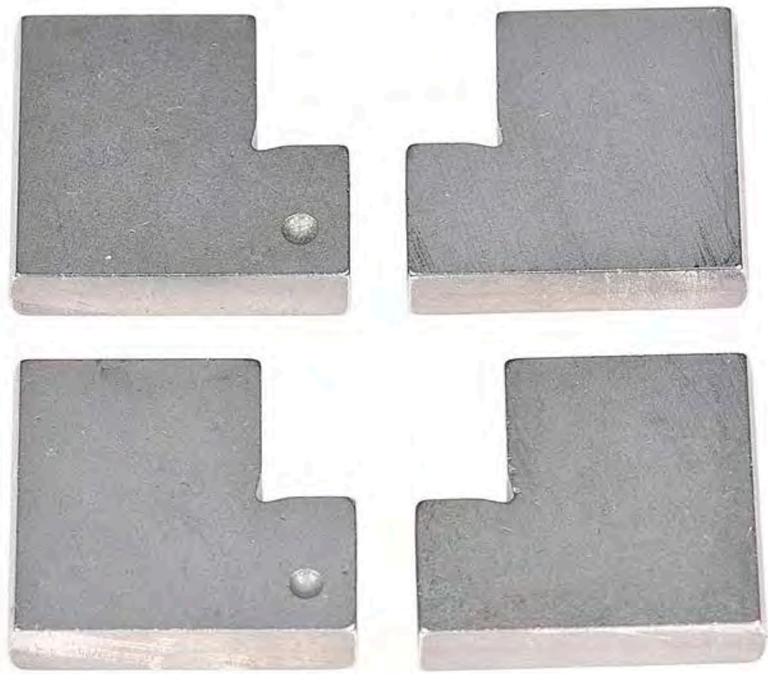
Table Q-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438888
Test Condition : FT-SPK w/22.5-mg/L DCI-4A @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing wear	1
LINER	90% Wear	3.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	2
REGULATOR PISTON	Wear with scuffing	2.5
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Polishing wear and light scuffing	2.5
PLUNGERS	Scuffing wear	3
SHOES	Dimple, light waer from leaf spring contact	2
ROLLERS	Wear marks over 100% of length	3
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Polishing wear	1.5
THRUST WASHER	Groove from weight contact	2
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Polishing wear and brown deposits	2
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scorring wear	3
HOUSING	Brown deposit stains	1
	AVERAGE DEMERIT RATINGS	1.935

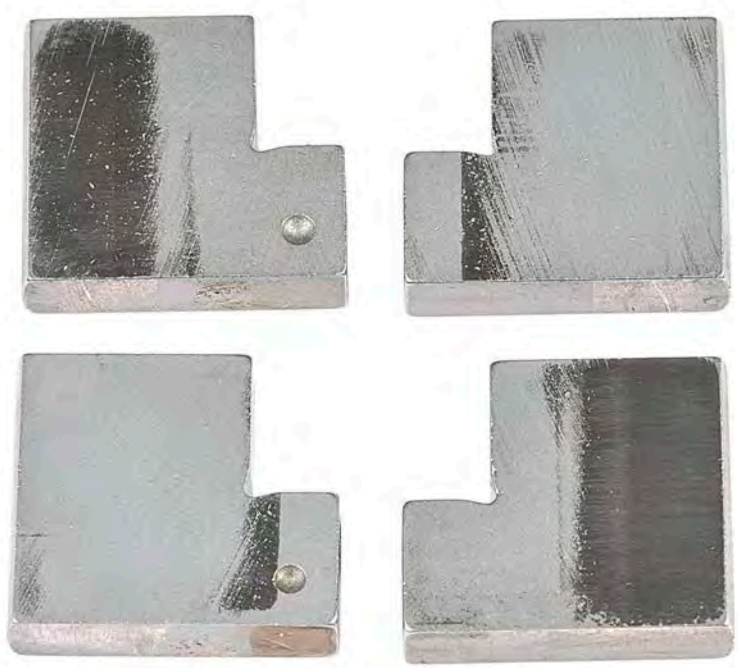
Table Q-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438889
Test Condition : FT-SPK w/22.5-mg/L DCI-4A @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing wear	1
LINER	80% Wear	3
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	2
REGULATOR PISTON	Wear with scuffing	2.5
ROTOR	Wear at distributor ports	2.5
ROTOR RETAINERS	Wear from rotor contact	3
DELIVERY VALVE	Polishing wear and light scuffing	2.5
PLUNGERS	Scuffing wear	2.5
SHOES	Dimple, light waer from leaf spring contact	1.5
ROLLERS	Wear marks over 100% of length	3
LEAF SPRING	Wear from shoe contact	2
CAM RING	Polishing wear	1
THRUST WASHER	Groove from weight contact	2
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2.5
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Polishing wear	2
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scorring wear	3
HOUSING	Brown deposit stains	1
	AVERAGE DEMERIT RATINGS	1.957

PHOTOGRAPHS FOR LEFT PUMP



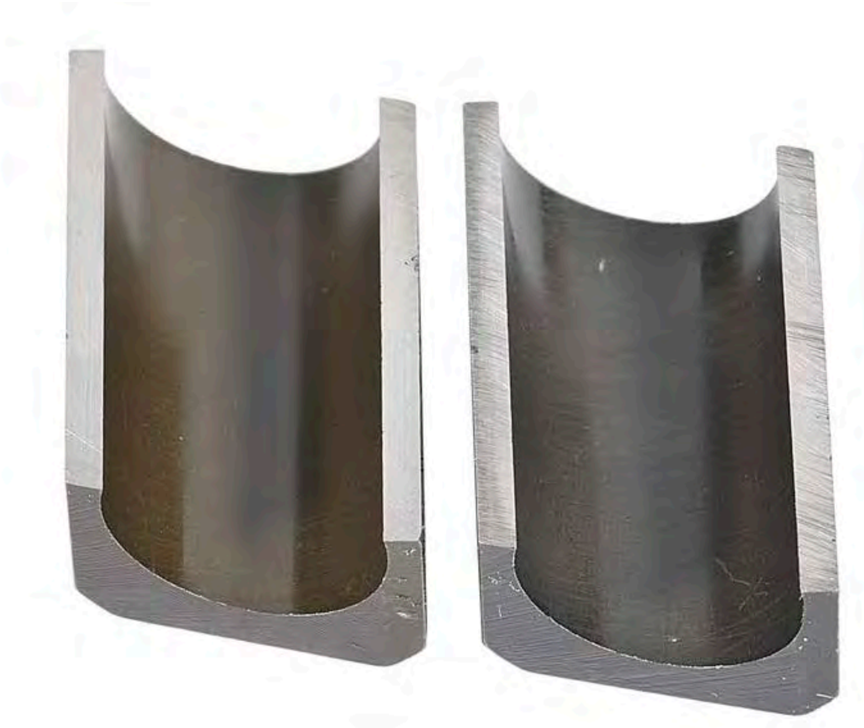
SN15438888 Transfer Pump Blades (Side) Before



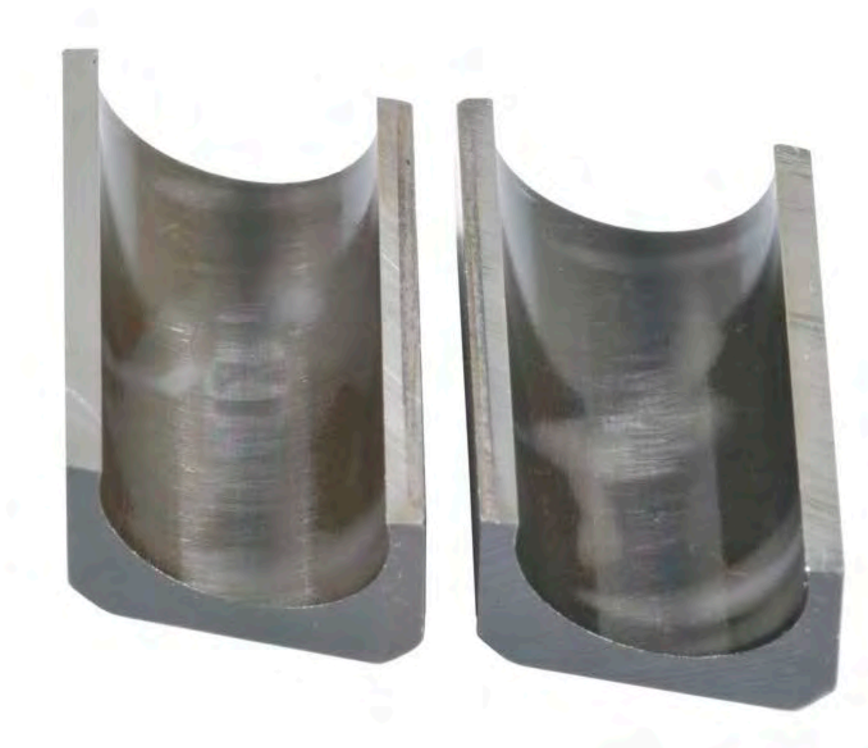
SN15438888 Transfer Pump Blades (Side) After

SN15438888 Transfer Pump Blades (Profile), Before

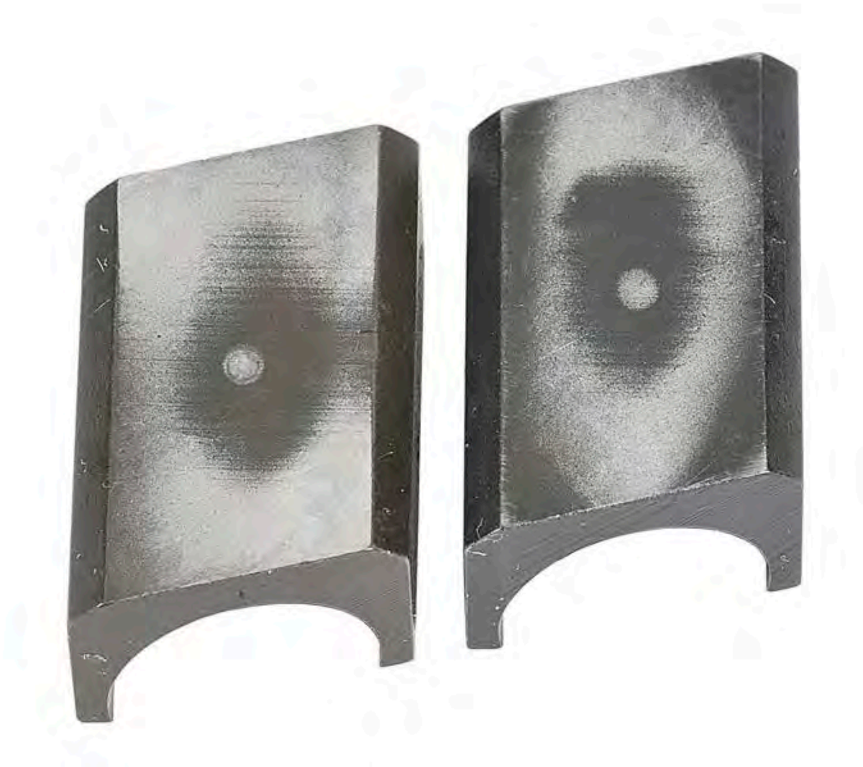
SN15438888 Transfer Pump Blades (Profile), After



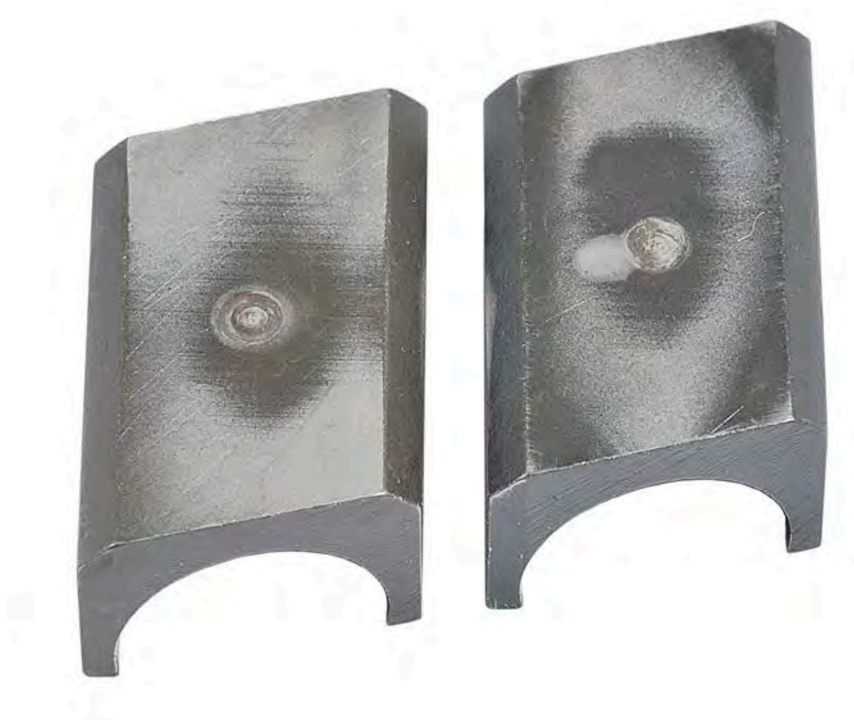
SN15438888 Shoes (Front), Before



SN15438888 Shoes (Front), After



SN15438888 Shoes (Back), Before



SN15438888 Shoes (Back), After

SN15438888 Rollers, Before

SN15438888 Rollers, After

SN15438888 Piston Plungers, Before

SN15438888 Piston Plungers, After

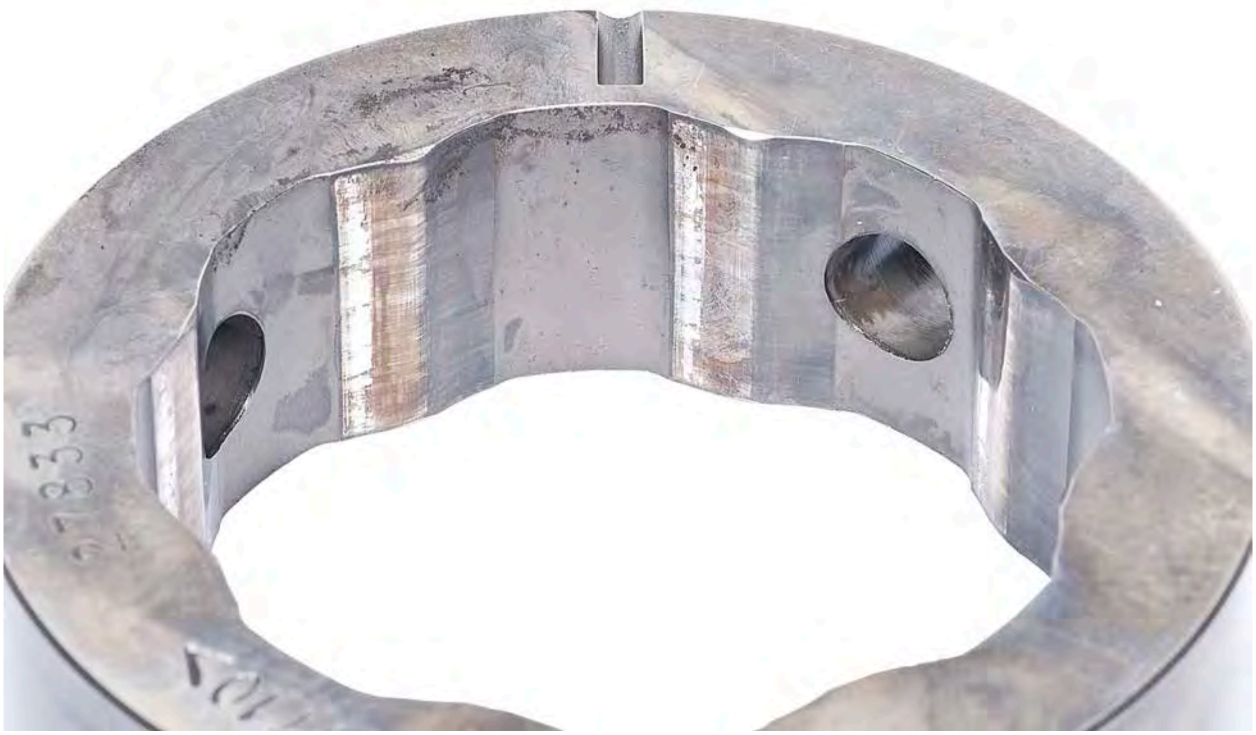
SN15438888 Thrust Washer, Before

SN15438888 Thrust Washer, After

SN15438888 Governor Weight, Before

SN15438888 Governor Weight, After

SN15438888 Cam Ring, Before



SN15438888 Cam Ring, After

SN15438888 Eccentric Ring, Before

SN15438888 Eccentric Ring, After


SN15438888 Rotor (Front), Before

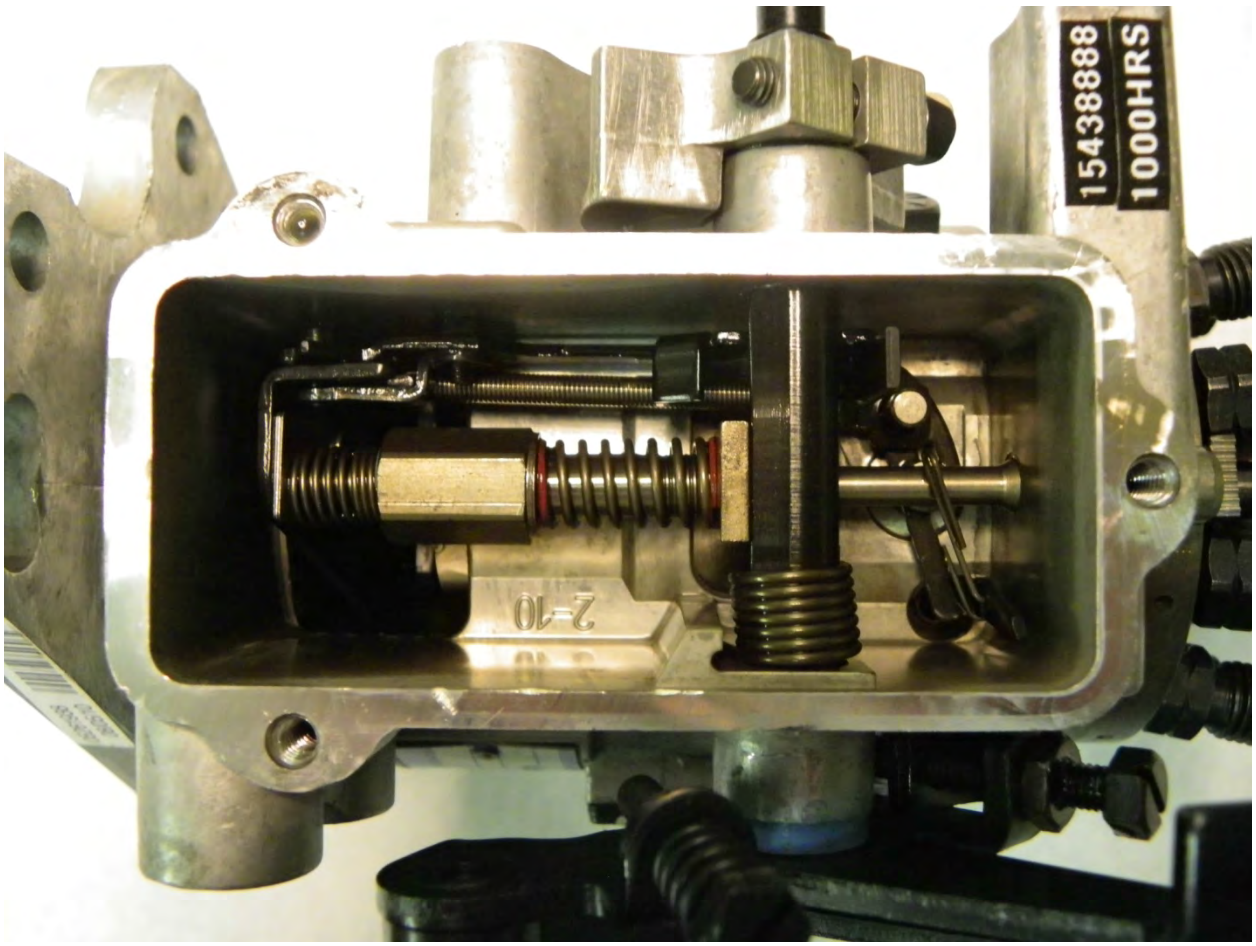

SN15438888 Rotor (Front), After

SN15438888 Rotor (Back), Before

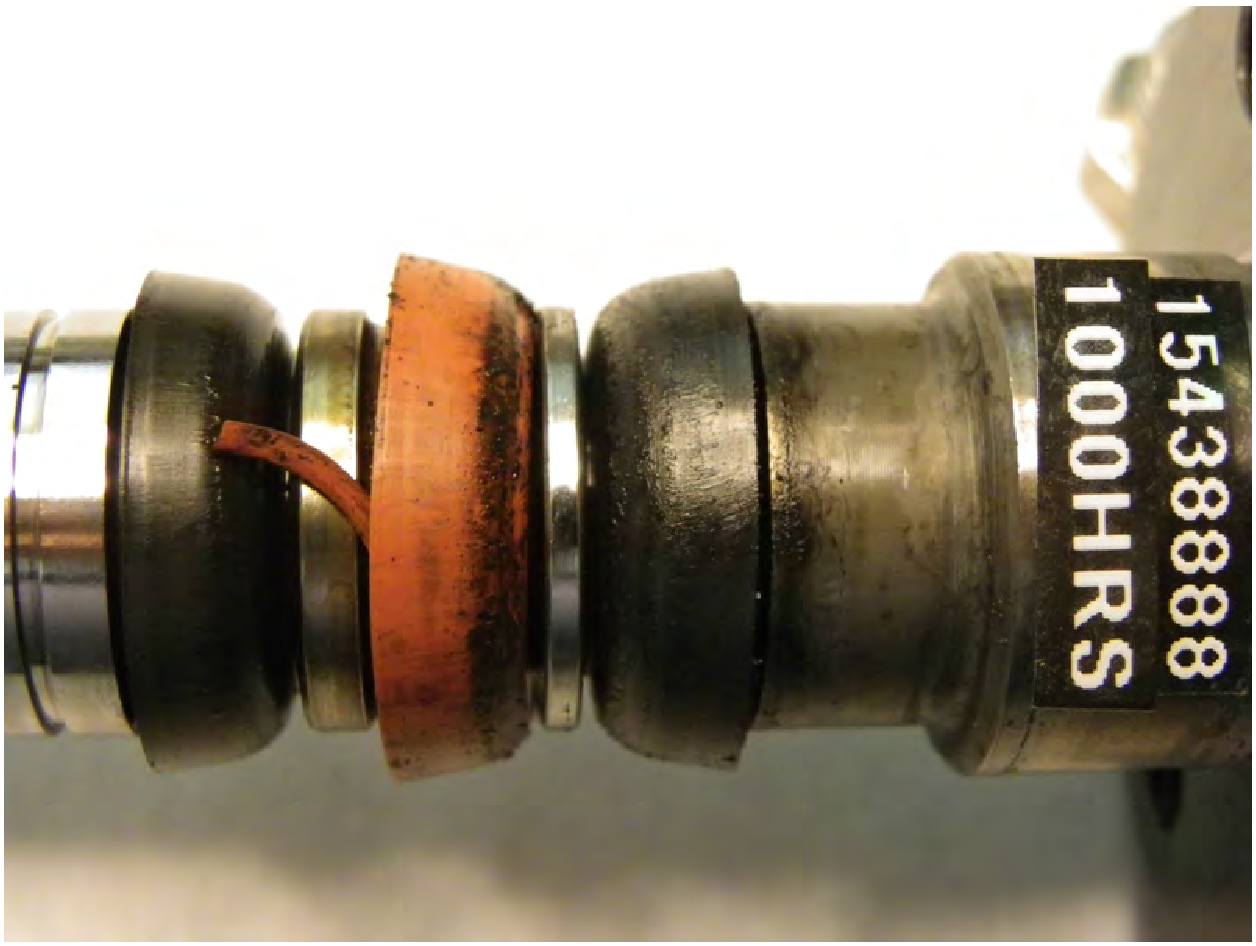
SN15438888 Rotor (Back), After

SN15438888 Drive Tang, Before

SN15438888 Drive Tang, After

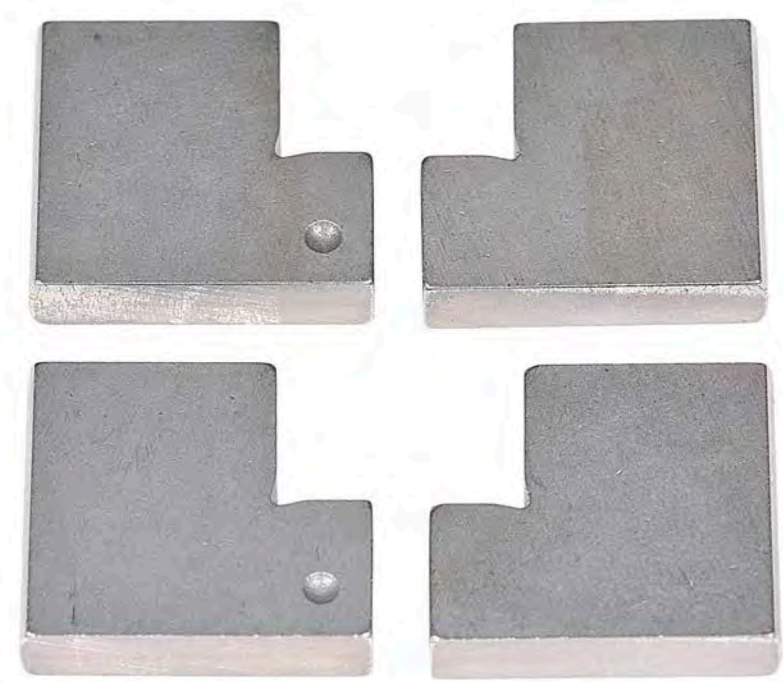


SN15438888 Governor Assembly, After



SN15438888 Drive Shaft Seals, After

PHOTOGRAPHS FOR RIGHT PUMP

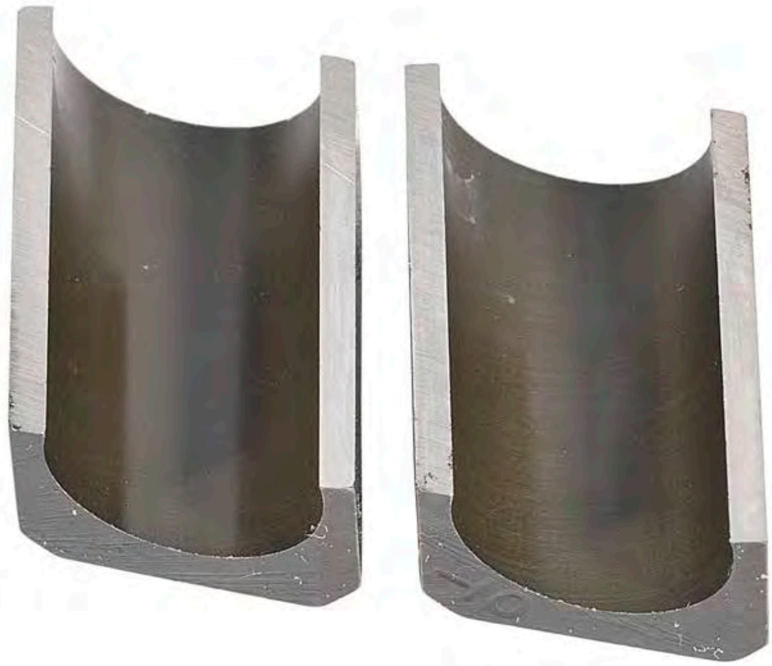


SN15438889 Transfer Pump Blades (Side) Before

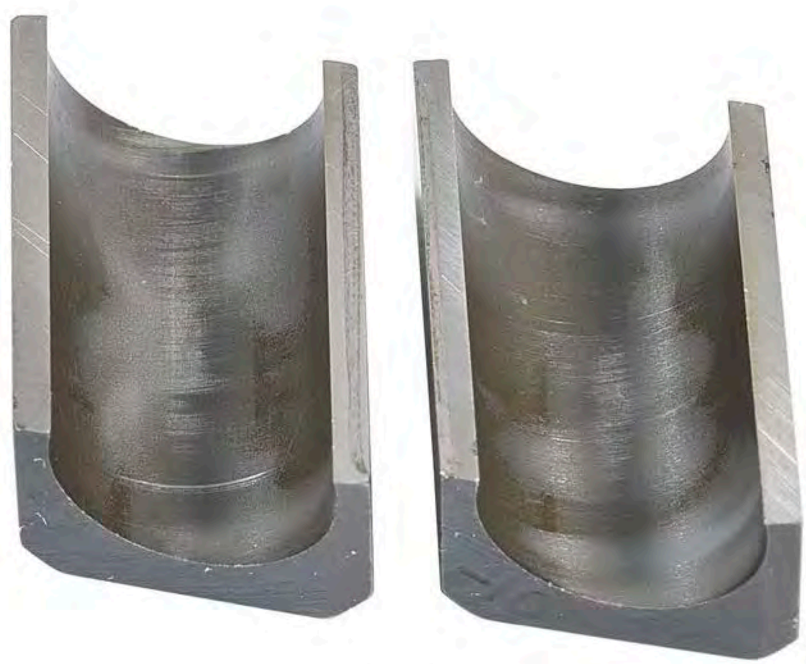
SN15438889 Transfer Pump Blades (Side) After

SN15438889 Transfer Pump Blades (Profile), Before

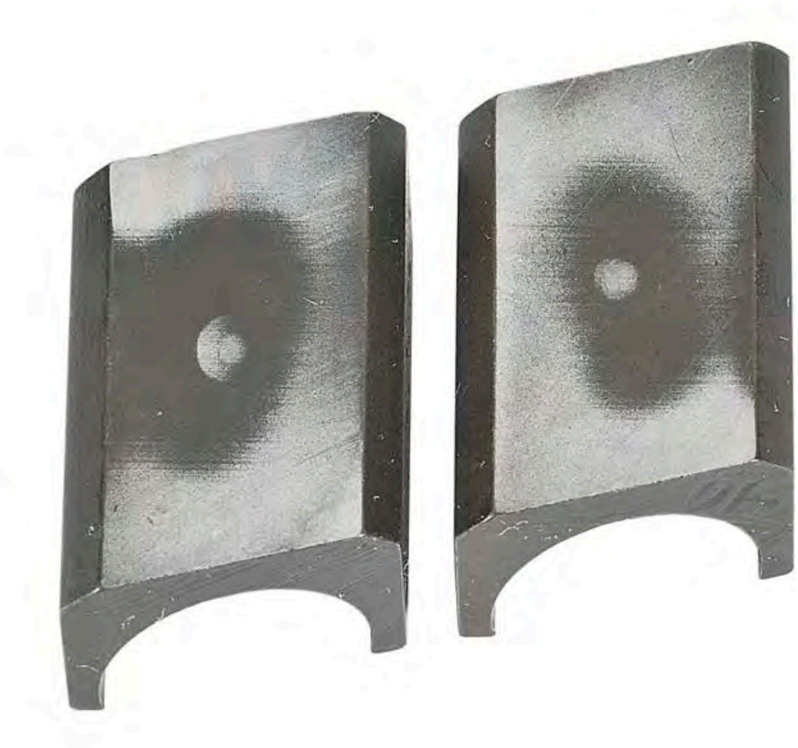
SN15438889 Transfer Pump Blades (Profile), After



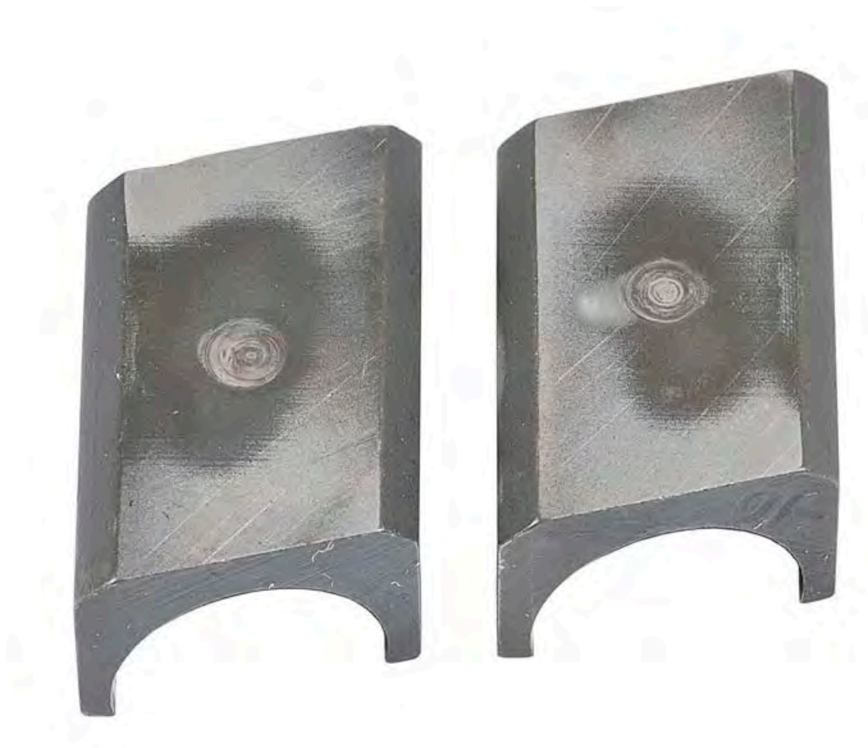
SN15438889 Shoes (Front), Before



SN15438889 Shoes (Front), After



SN15438889 Shoes (Back), Before



SN15438889 Shoes (Back), After

SN15438889 Rollers, Before

SN15438889 Rollers, After

SN15438889 Piston Plungers, Before

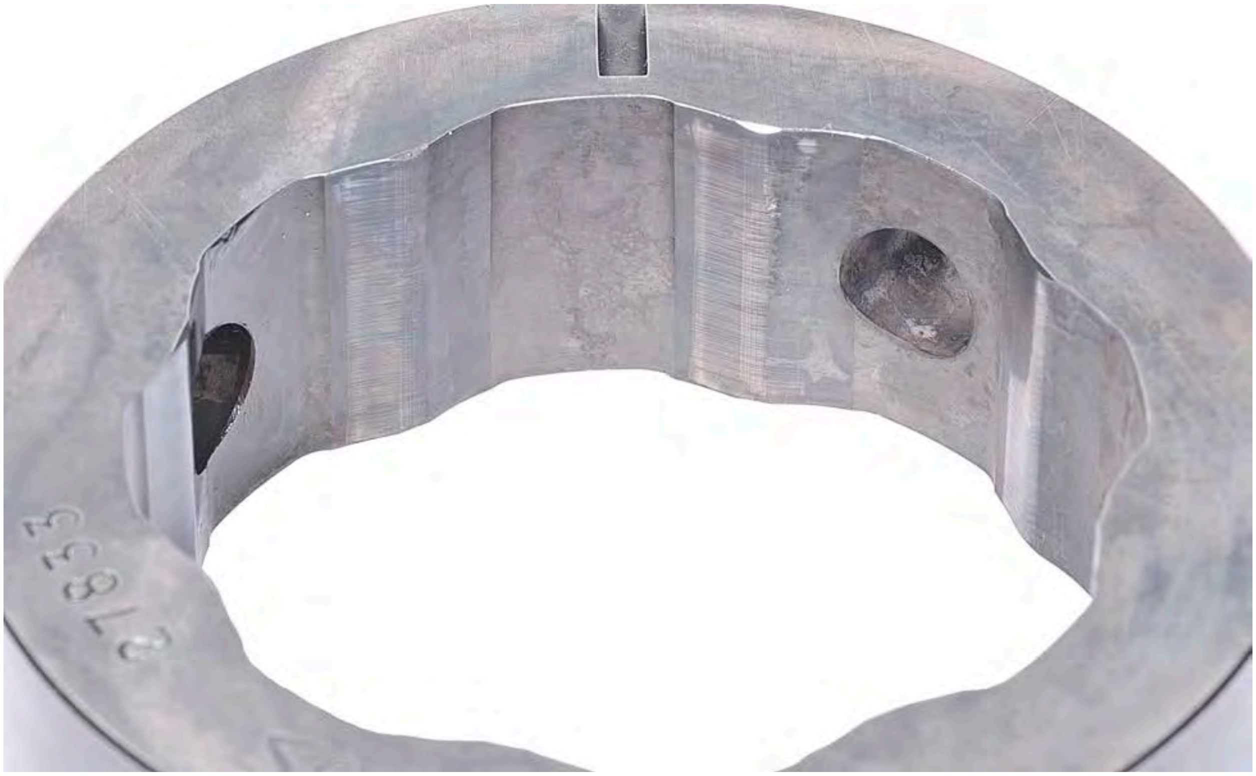
SN15438889 Piston Plungers, After

SN15438889 Thrust Washer, Before

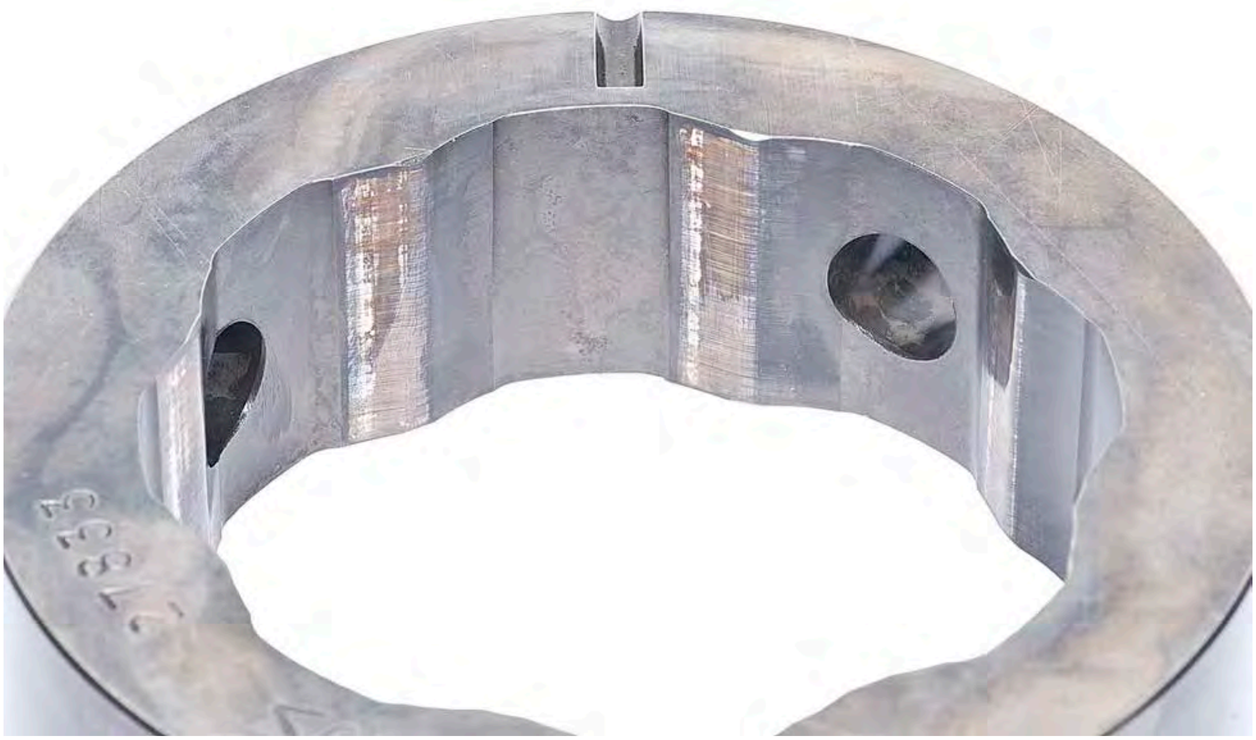
SN15438889 Thrust Washer, After

SN15438889 Governor Weight, Before

SN15438889 Governor Weight, After



SN15438889 Cam Ring, Before



SN15438889 Cam Ring, After

SN15438889 Eccentric Ring, Before

SN15438889 Eccentric Ring, After

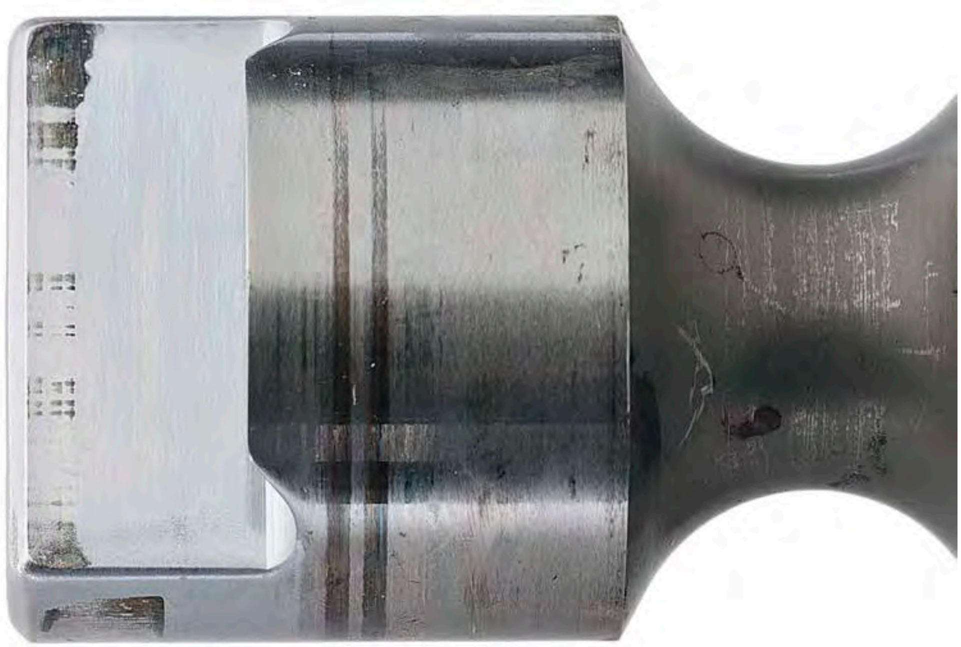
SN15438889 Rotor (Front), Before

SN15438889 Rotor (Front), After

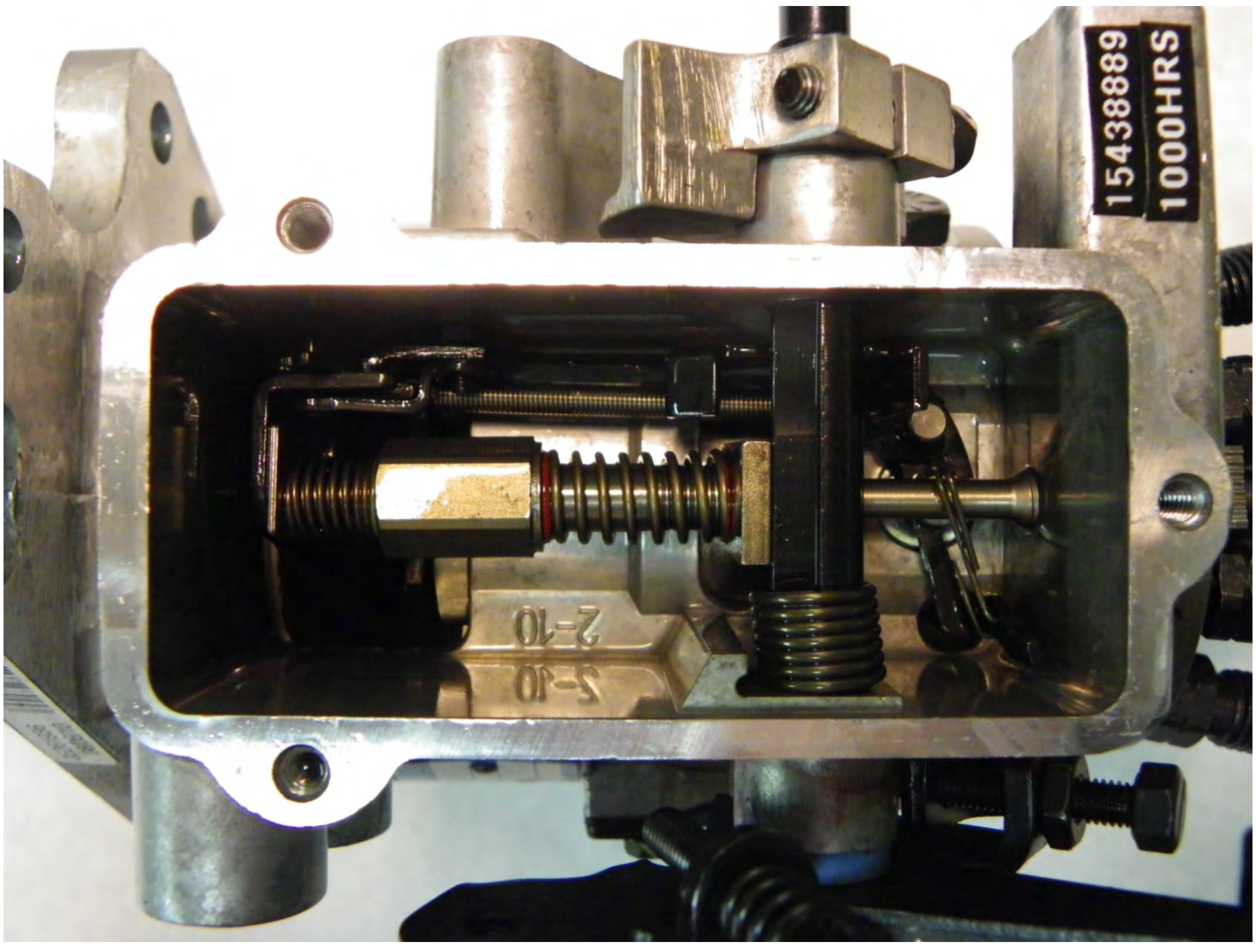
SN15438889 Rotor (Back), Before

SN15438889 Rotor (Back), After

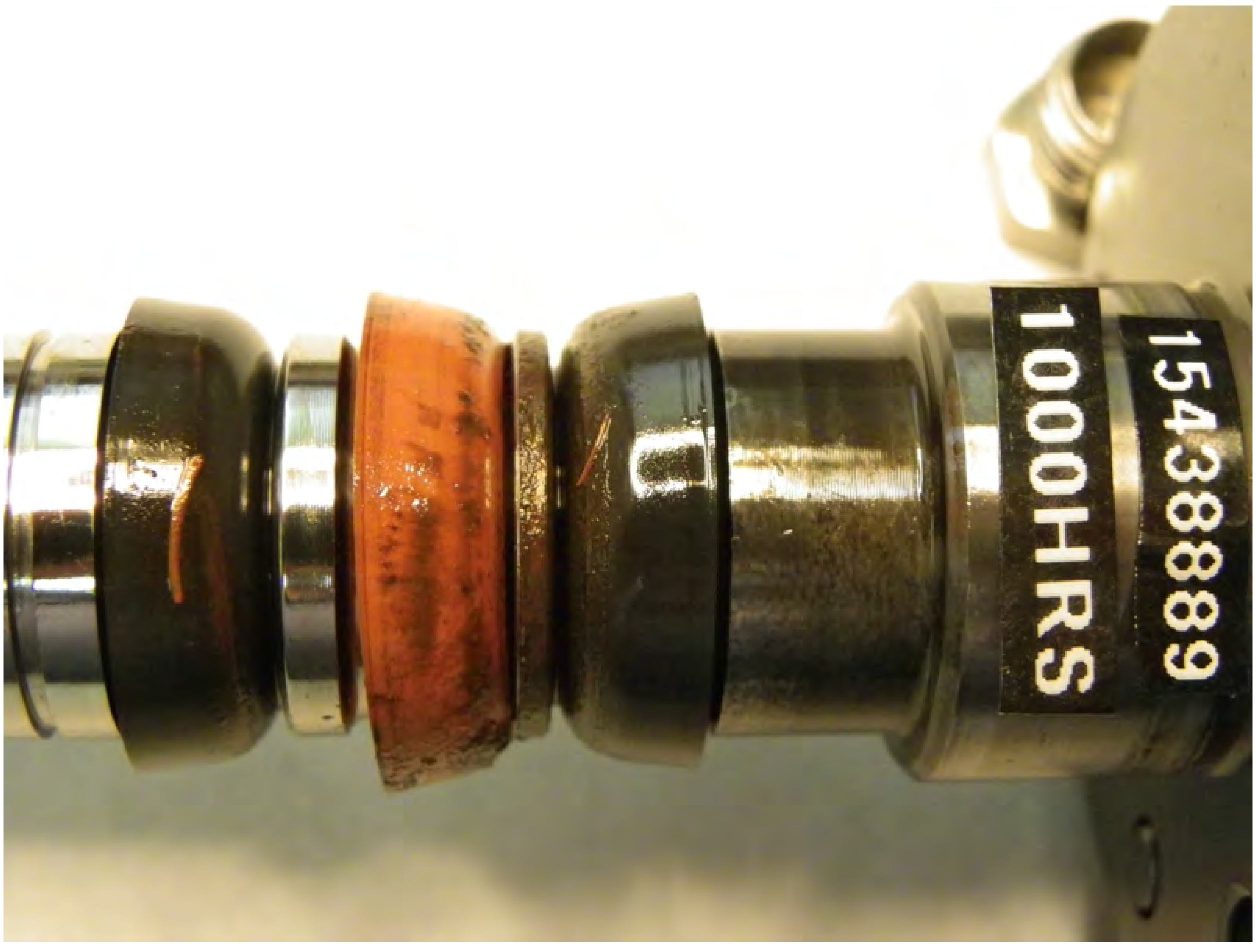
SN15438889 Drive Tang, Before



SN15438889 Drive Tang, After



SN15438889 Governor Assembly, After



SN15438889 Driveshaft Seals, After

APPENDIX R

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: FT-SPK with 22.5-mg/L DCI-4A
Test Number: C4T18-77-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: FT-SPK with 22.5-mg/L DCI-4A

Test Fuel ID: AL27892

Test Temperature: 77°C (170°F)

Test Number: C4T18-77-1000

Start of Test Date: February 17, 2012

End of Test Date: April 23, 2012

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure R-1.

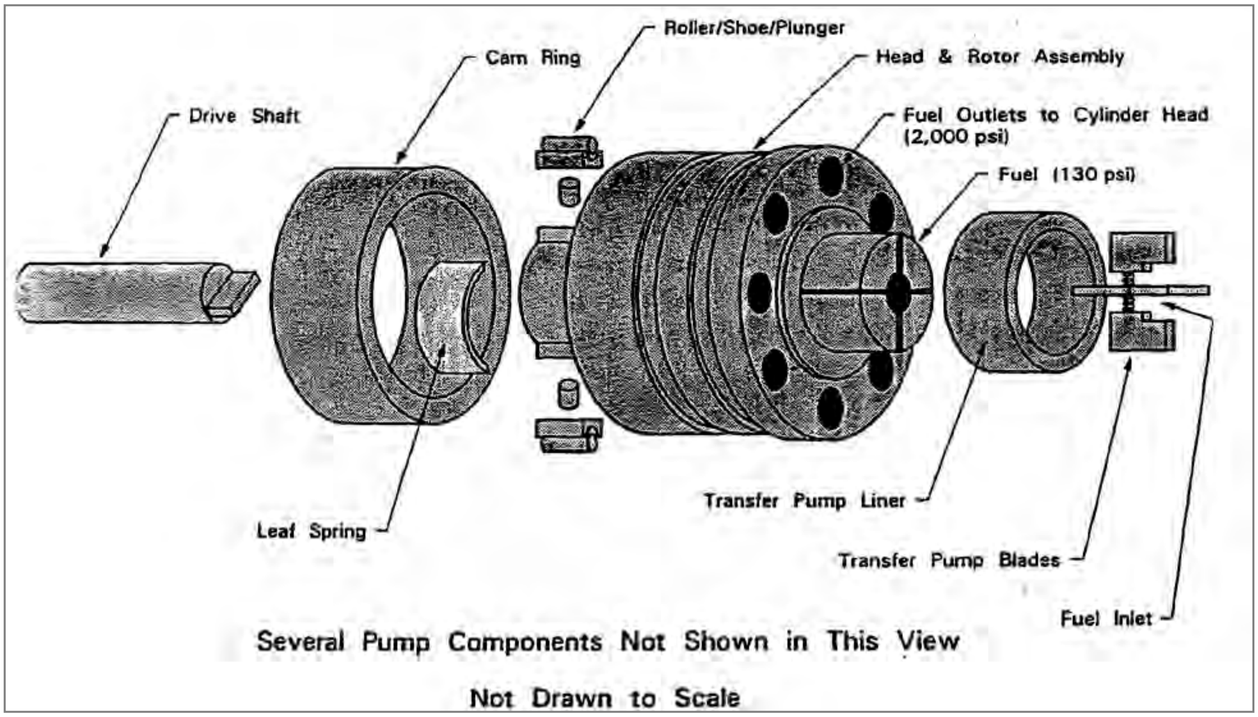


Figure R-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table R-1.

Table R-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	77 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table R-2.

Table R-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1701	2.51
FLO_R	Injected Flow-rate [mL/min]	752	21.8
FUELIN_P	Fuel Inlet Pressure [psig]	3.1	0.30
TRNS_P_R	Transfer Pump Pressure [psig]	68.6	0.89
HSG_P_R	Pump Housing Pressure [psig]	15.5	0.50
RTRN_T_R	Fuel Return Temperature [°C]	80.7	0.71
FUEL_T	Fuel Tank Temperature [°C]	27.6	42.6
FUELIN_T	Fuel Inlet Temperature [°C]	77	0.38

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure R-2 through Figure R-4.

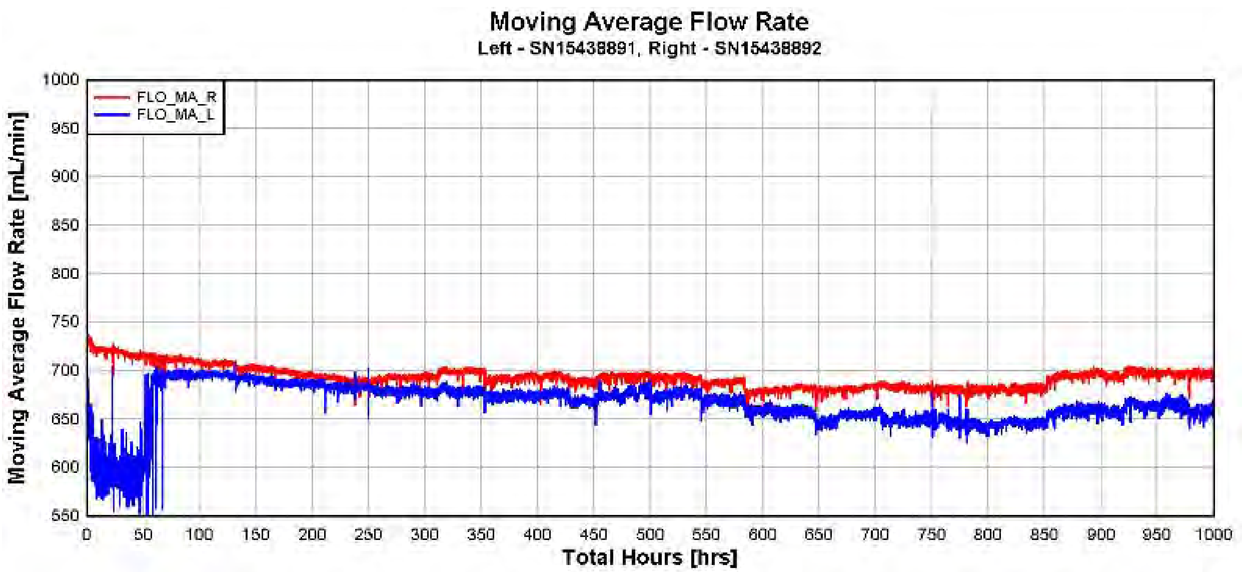


Figure R-2. Pump Flow, Moving Average

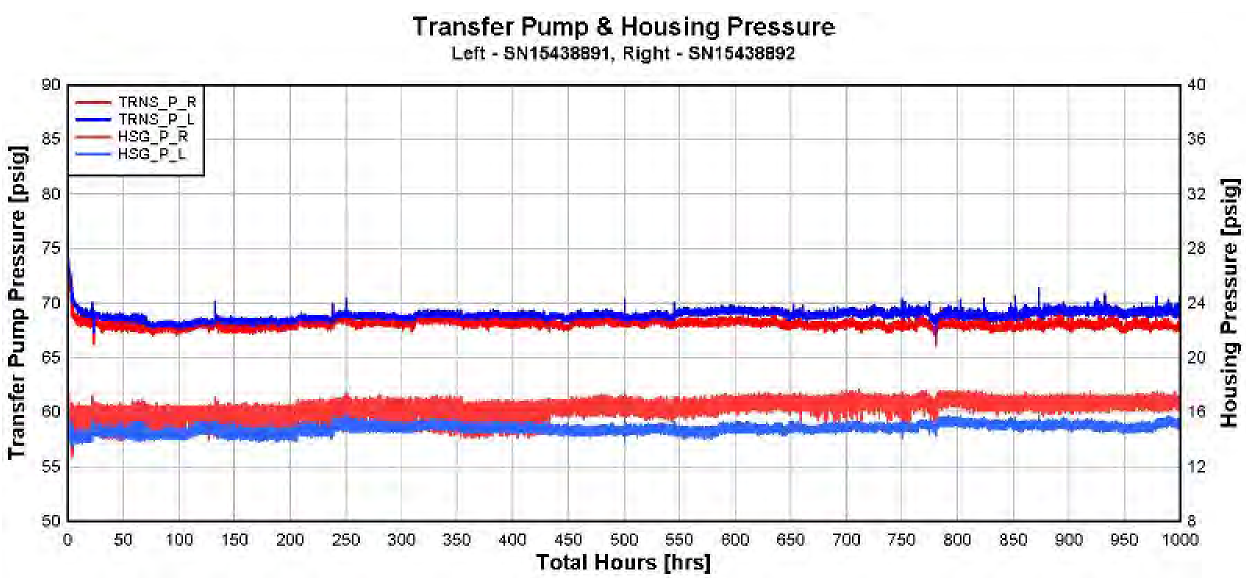


Figure R-3. Transfer Pump & Housing Pressure

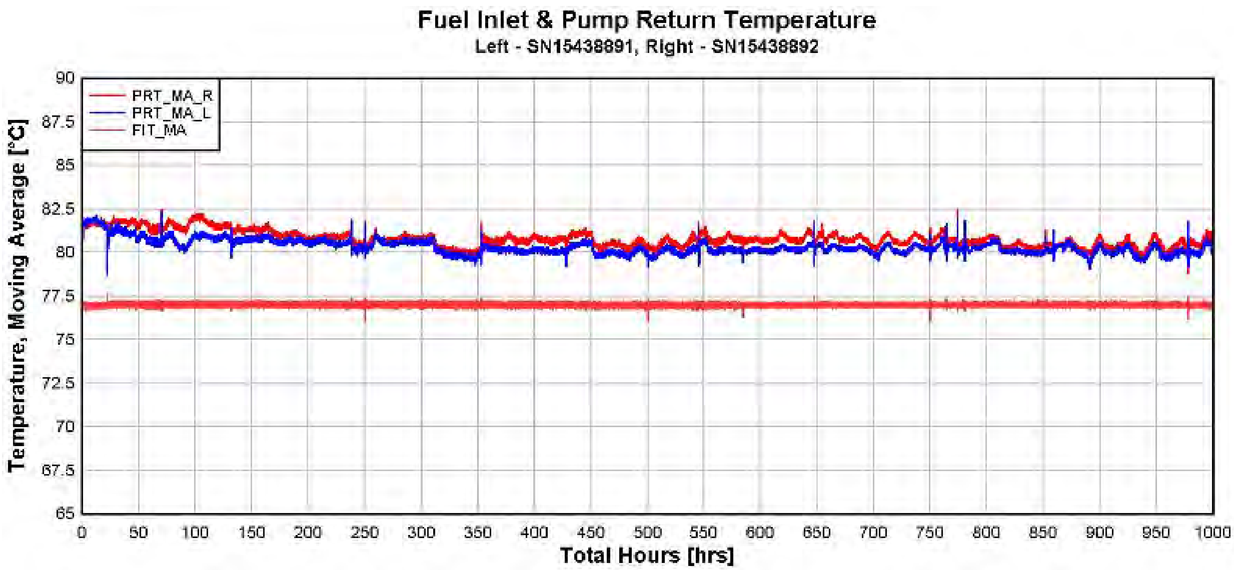


Figure R-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table R-3. (Note – Calibration data to be used as reference only).

Table R-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 18			Test Duration : 1000-hrs.		
Test Fuel : FT-SPK w/22.5-mg/L DCI-4A @ 170°F				SN : 15438891			SN : 15438892		
PUMP RPM	Description	Specification		Pump Duration : 1000.-hrs.			Pump Duration : 1000.-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	61 psi	1 psi	62 psi	61 psi	1 psi
	Return Fuel	225 cc	375 cc	340 cc	**382 cc**	-42 cc	340 cc	360 cc	-20 cc
350	Low Idle	12 cc	16 cc	15 cc	14 cc	1 cc	16 cc	**27 cc**	-11 cc
	Housing psi.	8 psi	12 psi	9.0 psi	9.5 psi	-.5 psi	11.0 psi	11.0 psi	.0 psi
	Advance	3.50°		4.05°	**3.03°**	1.02°	3.99°	4.13°	-.14°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	67.0 cc	**66.0 cc**	1.0 cc	67.0 cc	**66.0 cc**	1.0 cc
1600	WOT Fuel delivery	60 cc		63 cc	60 cc	3 cc	64 cc	62 cc	2 cc
	WOT Advance	2.50°	3.50°	3.07°	2.98°	.09°	3.03°	3.12°	-.09°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	23.0 cc	23.0 cc	.0 cc	22.0 cc	**21.0 cc**	1.0 cc
	Face Cam Advance	5.25°	7.25°	6.05°	6.28°	-.23°	6.20°	**7.26°**	-1.06°
	Low Idle	11.0°	12.0°	**10.8°**	**10.9°**	-.1°	**10.9°**	11.1°	-.1°
1825	Fuel Delivery	33 cc		39 cc	57 cc	-18 cc	39 cc	55 cc	-16 cc
1950	High Idle		15 cc	2 cc	3 cc	-1 cc	2 cc	3 cc	-1 cc
	Transfer pump psi.		125 psi	109 psi	106 psi	3 psi	106 psi	105 psi	1 psi
200	WOT Fuel Delivery	58 cc		59 cc	58 cc	1 cc	59 cc	59 cc	0 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		45 cc	46 cc	-1 cc	46 cc	48 cc	-2 cc
	Transfer pump psi.	16 psi		27 psi	26 psi	1 psi	28 psi	27 psi	1 psi
	Housing psi.	.0 psi	12 psi	9.0 psi	9 psi	0 psi	9 psi	9 psi	0 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table R-4 and Table R-5.

Table R-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438891	Test Number: 18	
Fuel Description : FT-SPK w/22.5-mg/L DCI-4A @ 170°F				
	Date:	1/0/1900	5/23/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000.-hrs.***	***Change***
Measurement 1	Mass (g)	3.2302	3.2231	-0.0071
Measurement 2		3.2304	3.2230	-0.0074
Measurement 3		3.2303	3.2230	-0.0073
Measurement 4		3.2305	3.2231	-0.0074
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2259	3.2165	-0.0094
Measurement 2		3.2258	3.2165	-0.0093
Measurement 3		3.2258	3.2166	-0.0092
Measurement 4		3.2259	3.2167	-0.0092
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2325	3.2170	-0.0155
Measurement 2		3.2324	3.2171	-0.0153
Measurement 3		3.2323	3.2171	-0.0152
Measurement 4		3.2323	3.2172	-0.0151
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2060	3.1919	-0.0141
Measurement 2		3.2060	3.1920	-0.0140
Measurement 3		3.2058	3.1918	-0.0140
Measurement 4		3.2058	3.1918	-0.0140
Average Measurements		***0-hrs.***	***1000.-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2304	3.2231	-0.0073
Transfer Pump Blade 2		3.2259	3.2166	-0.0093
Transfer Pump Blade 3		3.2324	3.2171	-0.0153
Transfer Pump Blade 4		3.2059	3.1919	-0.0140
	Roller to Roller (in)	1.9760	1.9737	-0.0023
	Eccentricity (in.)	0.0090	0.0100	0.0010
	Drive Backlash (In)	0.0050	0.0070	0.0020

Table R-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15438892	Test Number: 18	
Fuel Description : FT-SPK w/22.5-mg/L DCI-4A @ 170°F				
	Date:	1/0/1900	5/23/2012	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2665	3.2637	-0.0028
Measurement 2		3.2665	3.2635	-0.0030
Measurement 3		3.2665	3.2635	-0.0030
Measurement 4		3.2664	3.2635	-0.0029
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2852	3.2809	-0.0043
Measurement 2		3.2852	3.2810	-0.0042
Measurement 3		3.2853	3.2810	-0.0043
Measurement 4		3.2852	3.2810	-0.0042
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2181	3.2160	-0.0021
Measurement 2		3.2180	3.2160	-0.0020
Measurement 3		3.2180	3.2159	-0.0021
Measurement 4		3.2180	3.2159	-0.0021
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2823	3.2792	-0.0031
Measurement 2		3.2824	3.2793	-0.0031
Measurement 3		3.2824	3.2792	-0.0032
Measurement 4		3.2824	3.2793	-0.0031
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2665	3.2636	-0.0029
Transfer Pump Blade 2		3.2852	3.2810	-0.0042
Transfer Pump Blade 3		3.2180	3.2160	-0.0021
Transfer Pump Blade 4		3.2824	3.2793	-0.0031
	Roller to Roller (in)	1.9761	1.9751	-0.0010
	Eccentricity (in.)	0.0090	0.0110	0.0020
	Drive Backlash (In)	0.0050	0.0070	0.0020

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table R-6.

Table R-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation
6.5L Fuel Injector Test Inspection

Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
18	15438891	FT-SPK w/22.5-mg/L DCI-4A @ 170°F	18-1	2100	1900	Pass	Pass	Pass	Pass	Pass	Pass
			18-2	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			18-3	2150	1775	Pass	Pass	Pass	Pass	Pass	Pass
			18-4	2175	1950	Pass	Pass	Pass	Pass	Pass	Pass
			18-5	2175	1875	Pass	Pass	Pass	Pass	Pass	Pass
			18-6	2175	1800	Pass	Pass	Pass	Pass	Pass	Pass
			18-7	2150	1800	Pass	Pass	Pass	Pass	Pass	Pass
			18-8	2150	1975	Pass	Pass	Pass	Pass	Pass	Pass
18	15438892	FT-SPK w/22.5-mg/L DCI-4A @ 170°F	18-11	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			18-12	2125	1850	Pass	Pass	Pass	Pass	Pass	Pass
			18-13	2225	1900	Pass	Pass	Pass	Pass	Pass	Pass
			18-14	2150	1825	Pass	Pass	Pass	Pass	Pass	Pass
			18-15	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			18-16	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			18-17	2125	1800	Pass	Pass	Pass	Pass	Pass	Pass
			18-18	2100	1900	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table R-7 and Table R-8.

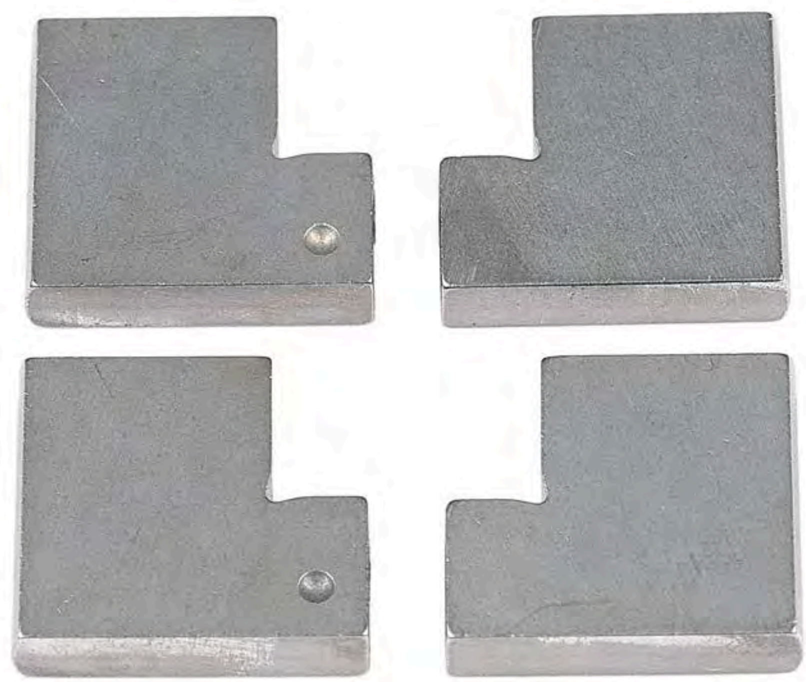
Table R-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438891
Test Condition : FT-SPK w/22.5-mg/L DCI-4A @ 170°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2
BLADE SPRINGS	Rubbing wear	1
LINER	60% Wear	2
TRANSFER PUMP REGULATOR	Waer mark from rotor, light polishing	2
REGULATOR PISTON	Polishing wear, light scuffing	2
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	2.5
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Polishing wear and light scratces	2.5
SHOES	Dimple, light waer from leaf spring contact	1.5
ROLLERS	Discolored and light scorring	1
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Polishing wear	1
THRUST WASHER	Groove from weight contact	2
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Polishing wear. Light brown deposit	1
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scorring wear	3
HOUSING	Light brown stain inside	1
	AVERAGE DEMERIT RATINGS	1.630

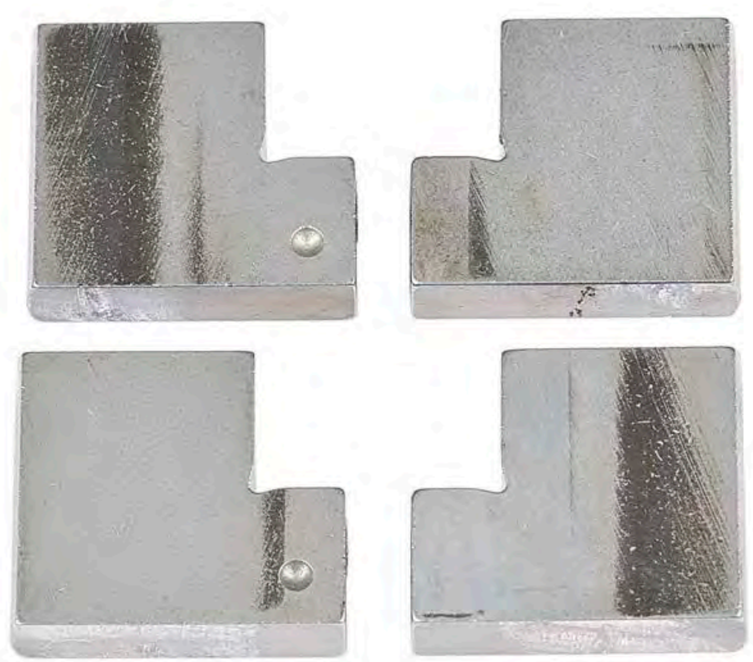
Table R-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15438892
Test Condition : FT-SPK w/22.5-mg/L DCI-4A @ 170°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2
BLADE SPRINGS	Rubbing wear	1
LINER	60% Wear	2
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	2
REGULATOR PISTON	Polishing wear	2
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Polishing wear	1.5
PLUNGERS	Polishing wear and light scratces	3
SHOES	Dimple, light waer from leaf spring contact	1.5
ROLLERS	Normal	1
LEAF SPRING	Wear from shoe contact	1.5
CAM RING	Polishing wear	1
THRUST WASHER	Groove from weight contact	2
THRUST SLEEVE	Normal	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Polishing wear. Light brown deposits	1.5
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scoring wear	3
HOUSING	Light brown stains	1
	AVERAGE DEMERIT RATINGS	1.630

PHOTOGRAPHS FOR LEFT PUMP



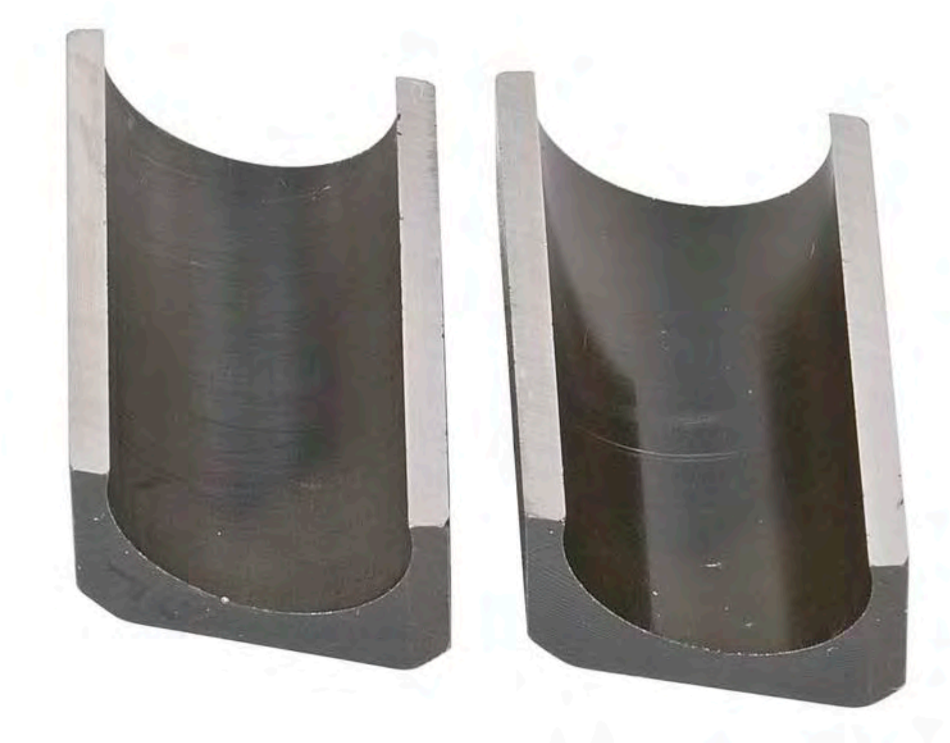
SN15438891 Transfer Pump Blades (Side), Before



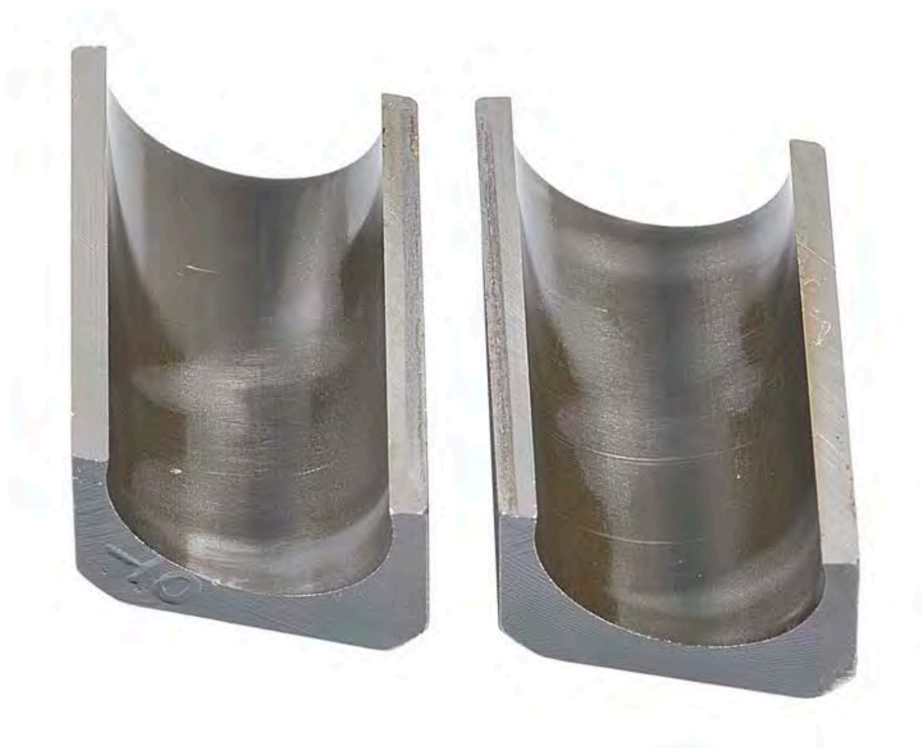
SN15438891 Transfer Pump Blades (Side), After

SN15438891 Transfer Pump Blades (Profile), Before

SN15438891 Transfer Pump Blades (Profile), After



SN15438891 Shoes (Front), Before



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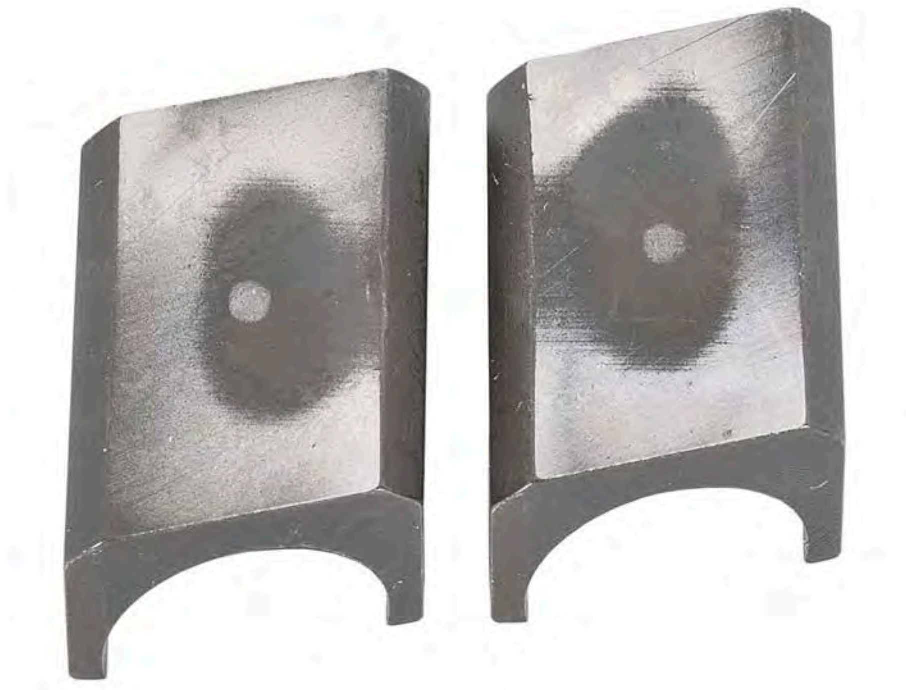

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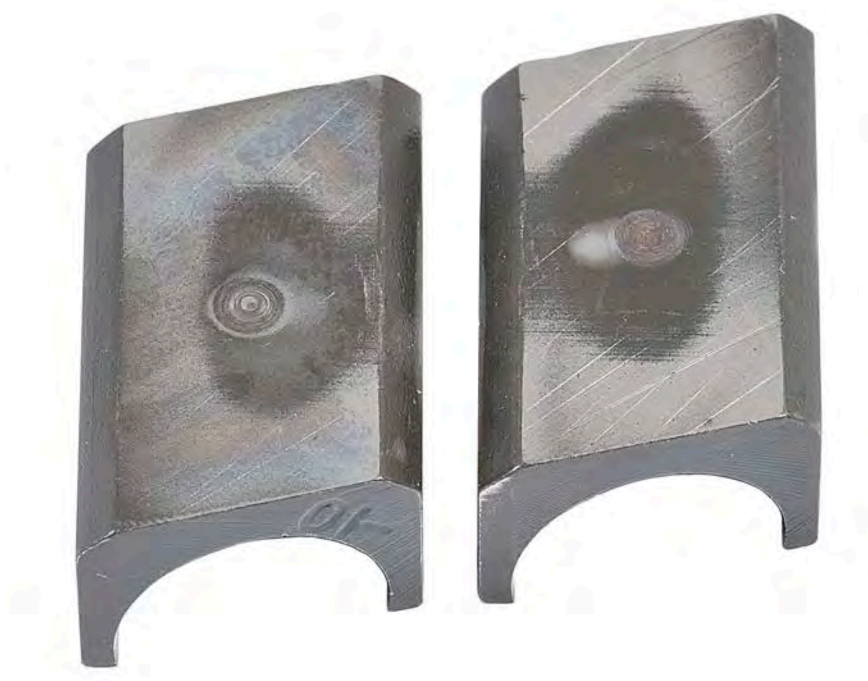


SN15438891 Shoes (Back), After

SN15438891 Rollers, Before

SN15438891 Rollers, After

SN15438891 Piston Plungers, Before

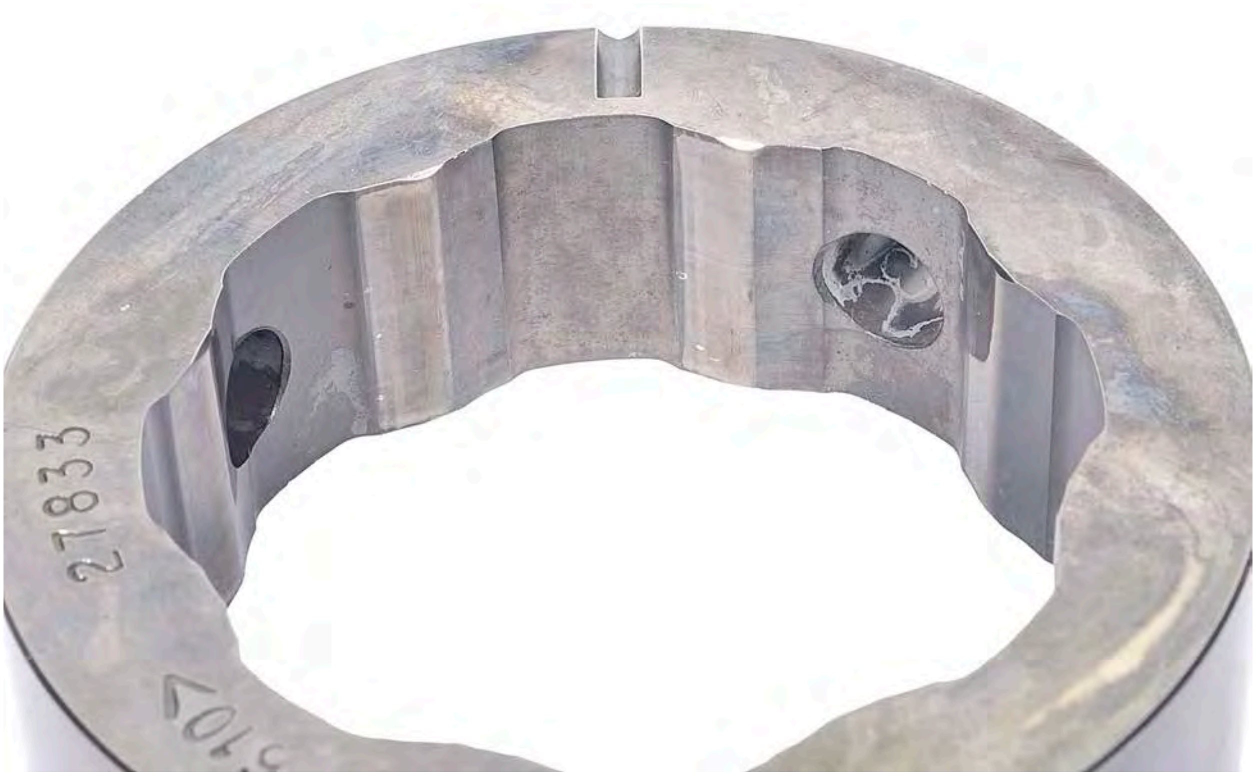
SN15438891 Piston Plungers, After

SN15438891 Thrust Washer, Before

SN15438891 Thrust Washer, After

SN15438891 Governor Weight, Before

SN15438891 Governor Weight, After



SN15438891 Cam Ring, Before

SN15438891 Cam Ring, After

SN15438891 Eccentric Ring, Before

SN15438891 Eccentric Ring, After

SN15438891 Rotor (Front), Before

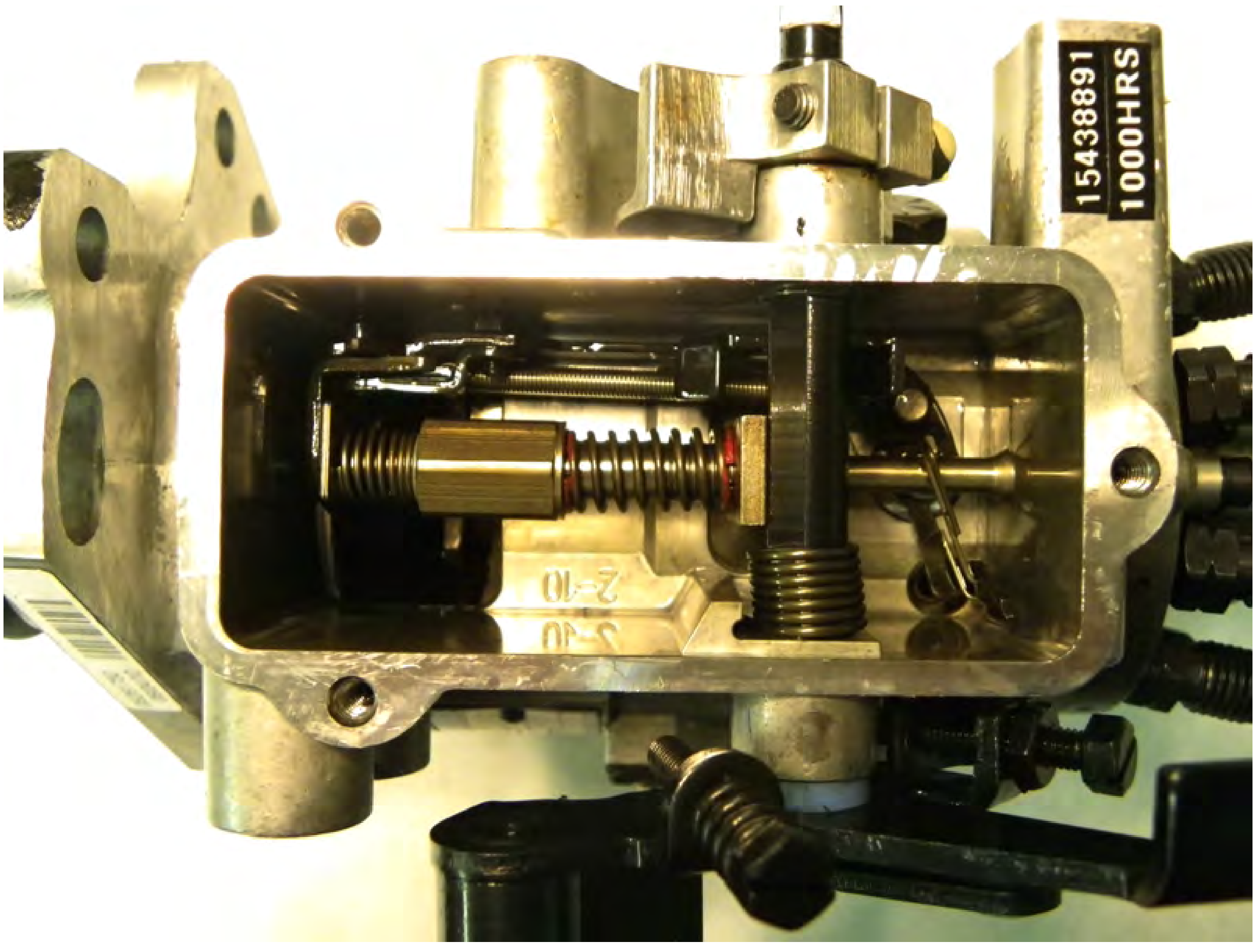
SN15438891 Rotor (Front), After

SN15438891 Rotor (Back), Before

SN15438891 Rotor (Back), After

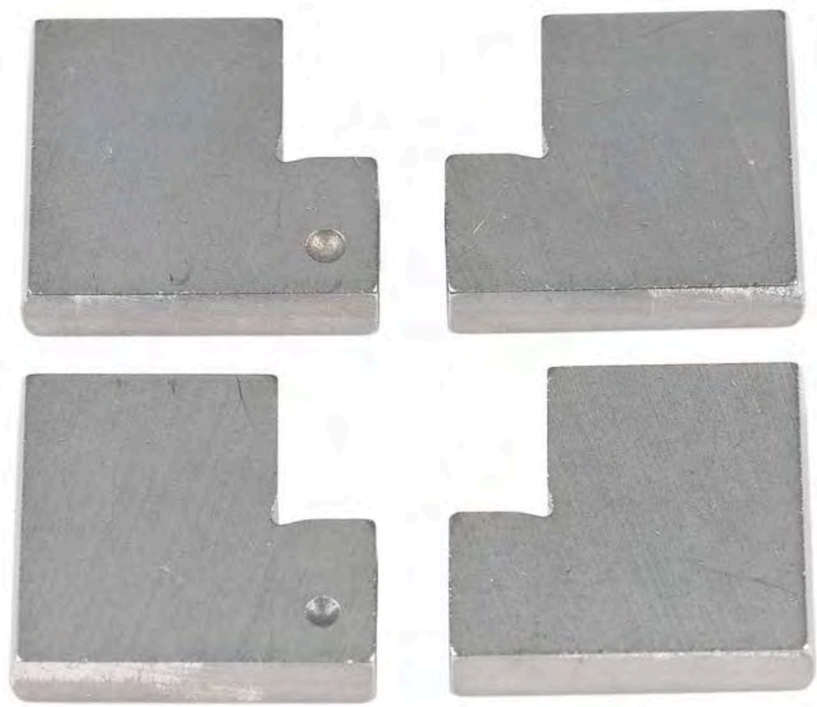
SN15438891 Drive Tang, Before

SN15438891 Drive Tang, After



SN15438891 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP

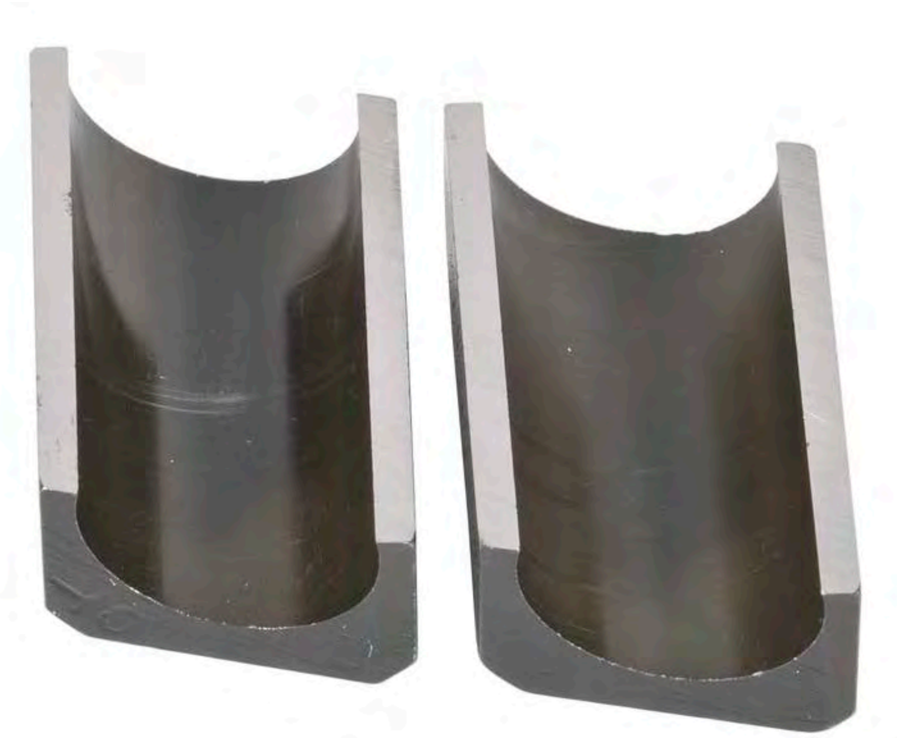


SN15438892 Transfer Pump Blades (Side), Before

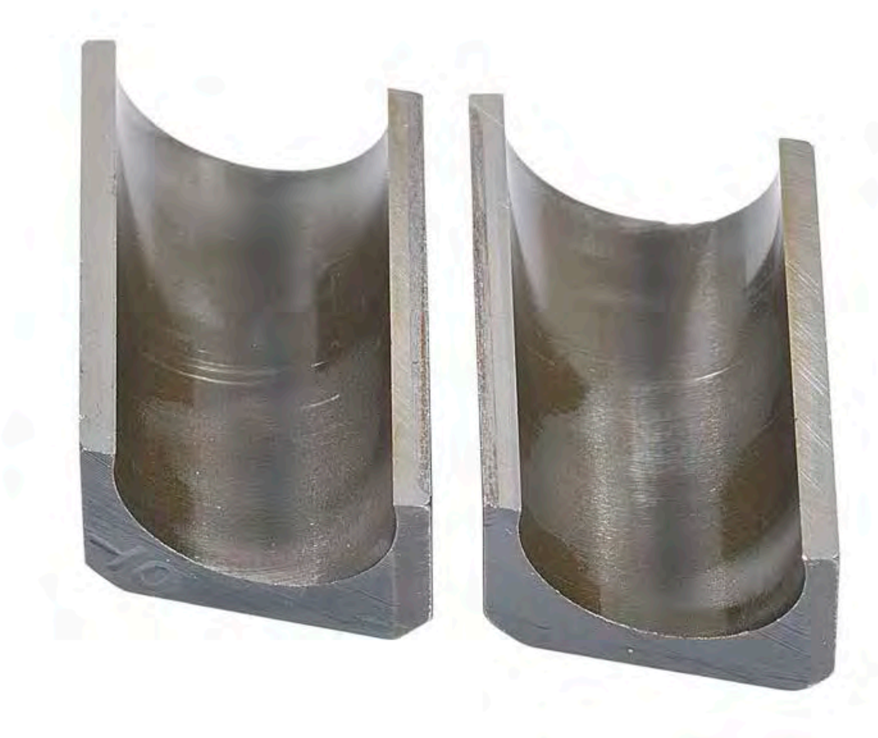
SN15438892 Transfer Pump Blades (Side), After

SN15438892 Transfer Pump Blades (Profile), Before

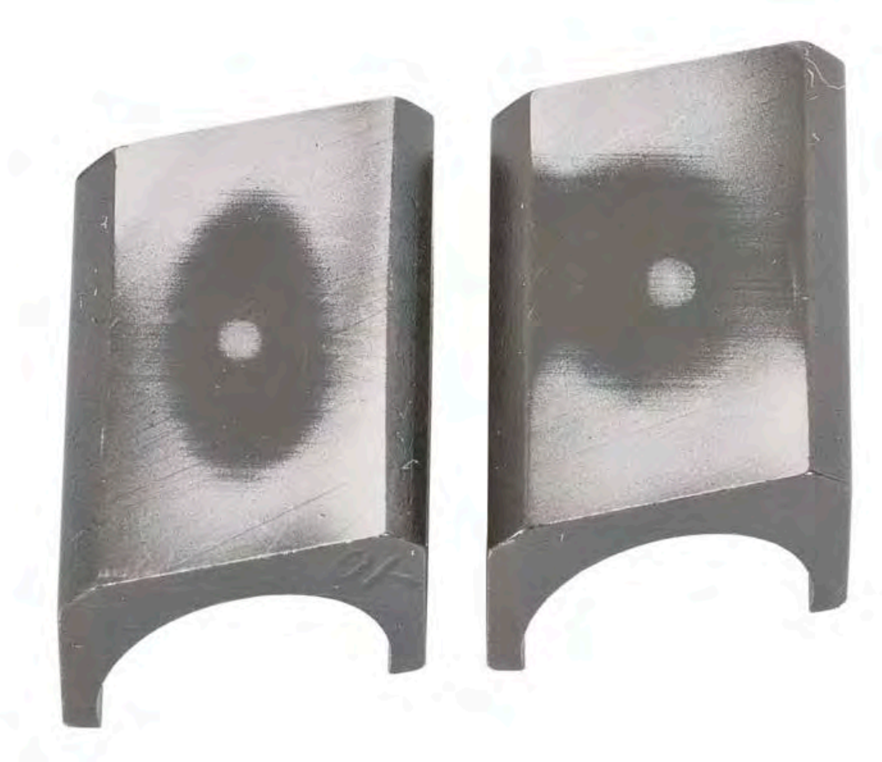
SN15438892 Transfer Pump Blades (Profile), After



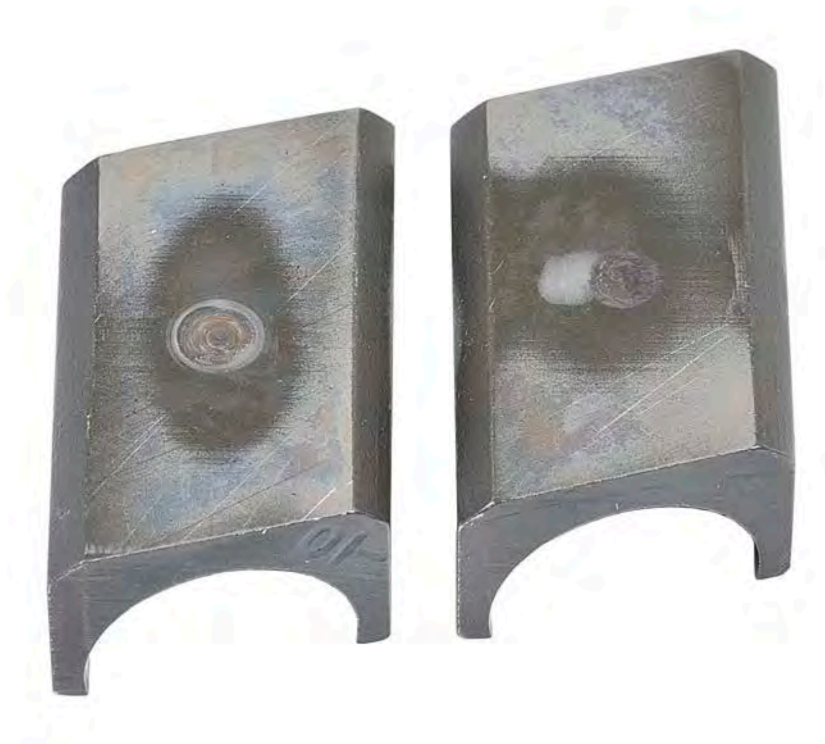
SN15438892 Shoes (Front), Before



SN15438892 Shoes (Front), After



SN15438892 Shoes (Back), Before



SN15438892 Shoes (Back), After

SN15438892 Rollers, Before

SN15438892 Rollers, After

SN15438892 Piston Plungers, Before

SN15438892 Piston Plungers, After

SN15438892 Thrust Washer, Before

SN15438892 Thrust Washer, After

SN15438892 Governor Weight, Before

SN15438892 Governor Weight, After

SN15438892 Cam Ring, Before

SN15438892 Cam Ring, After

SN15438892 Eccentric Ring, Before

SN15438892 Eccentric Ring, After

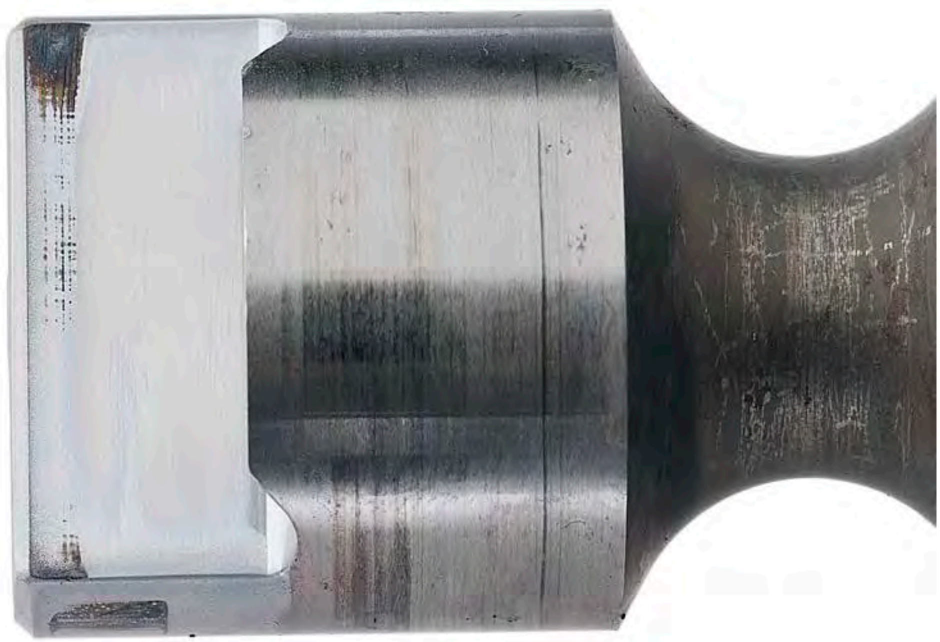
SN15438892Rotor (Front), Before

SN15438892 Rotor (Front), After

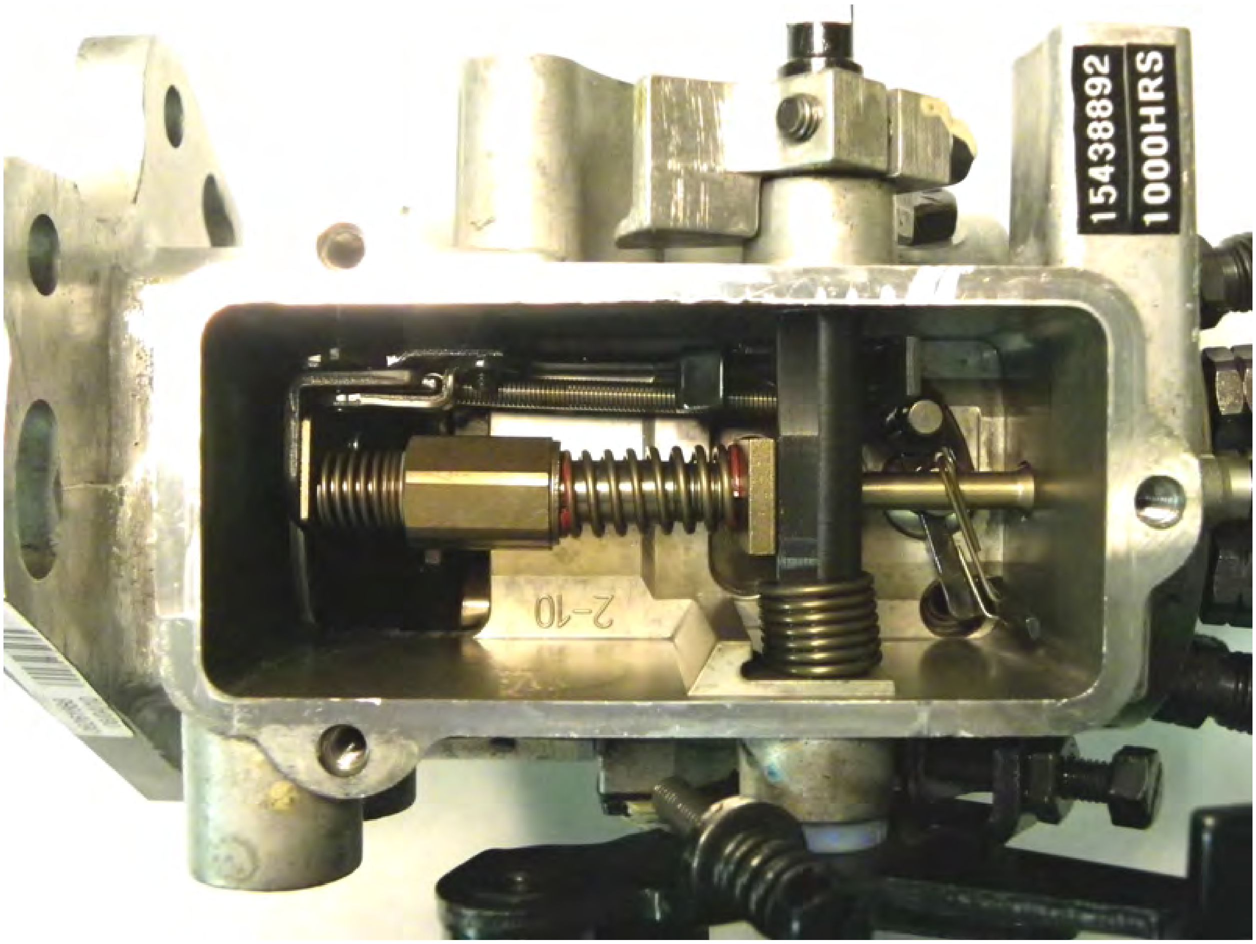
SN15438892 Rotor (Back), Before

SN15438892 Rotor (Back), After

SN15438892 Drive Tang, Before



SN15438892 Drive Tang, After



SN15438892 Governor Assembly

APPENDIX S

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: FT-SPK/Jet A-1 with 9-mg/L DCI-4A
Test Number: C4T19-40-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: FT-SPK/Jet A-1 with 9-mg/L DCI-4A

Test Fuel ID: AF7090

Test Temperature: 40°C (105°F)

Test Number: C4T19-40-1000

Start of Test Date: March 16, 2012

End of Test Date: May 16, 2012

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure S-1.

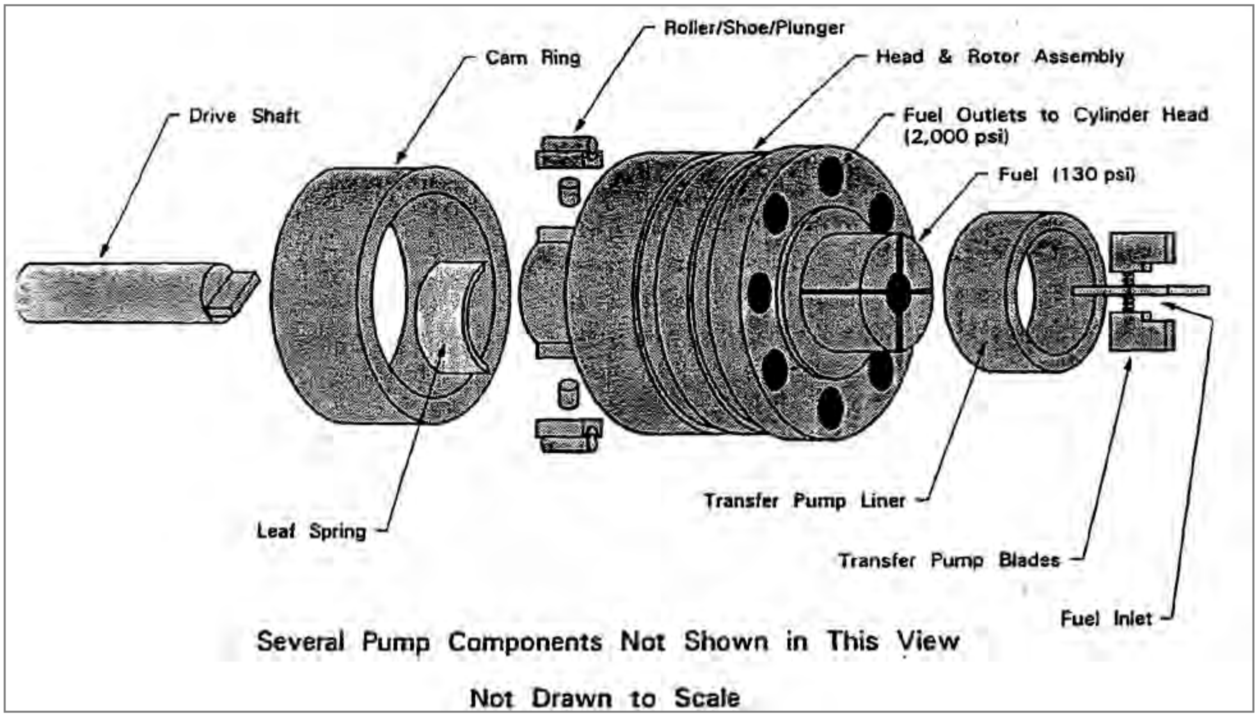


Figure S-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table S-1.

Table S-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	40 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table S-2.

Table S-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.0897
FLO_R	Injeted Flowrate [mL/min]	817.9	18.8
FUELIN_P	Fuel Inlet Pressure [psig]	2.7	0.4059
TRNS_P_R	Transfer Pump Pressure [psig]	72.4	0.957
HSG_P_R	Pump Housing Pressure [psig]	11.5	0.46
RTRN_T_R	Fuel Return Temperature [°C]	48.4	0.99
FUEL_T	Fuel Tank Temperature [°C]	30.1	2.09
FUELIN_T	Fuel Inlet Temperature [°C]	40.0	0.53

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure S-2 through Figure S-4.

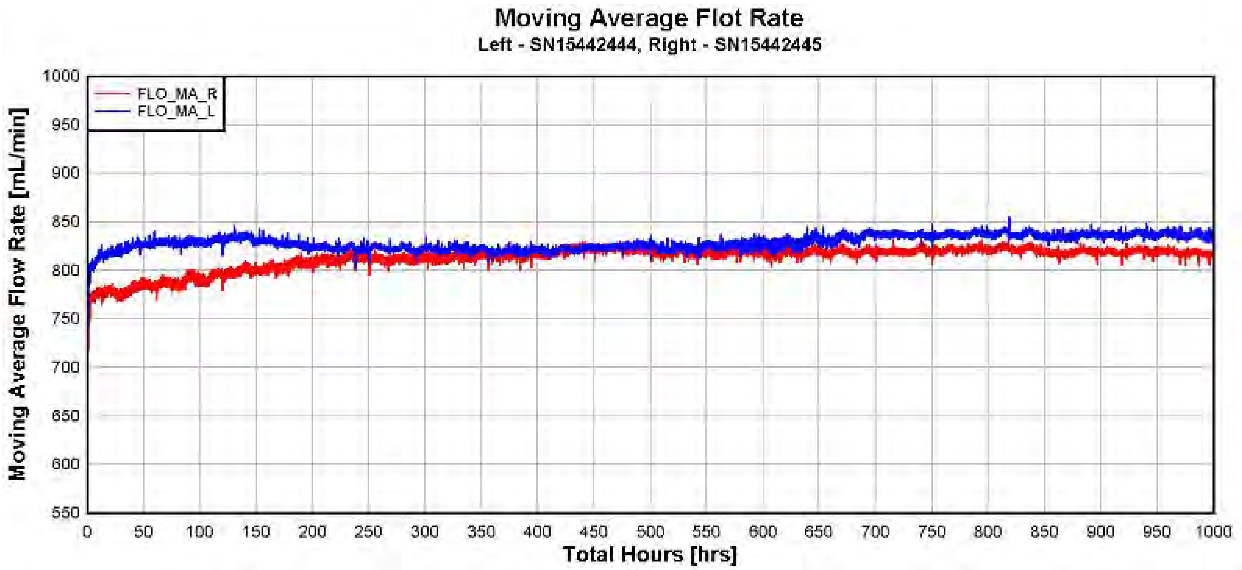


Figure S-2. Pump Flow, Moving Average

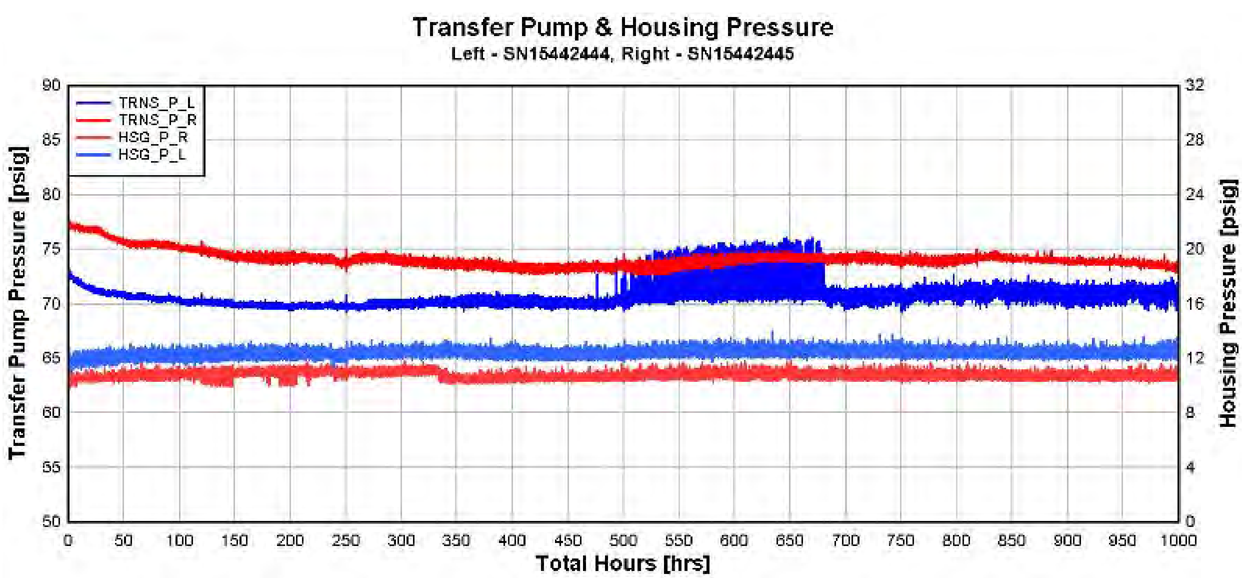


Figure S-3. Transfer Pump & Housing Pressure

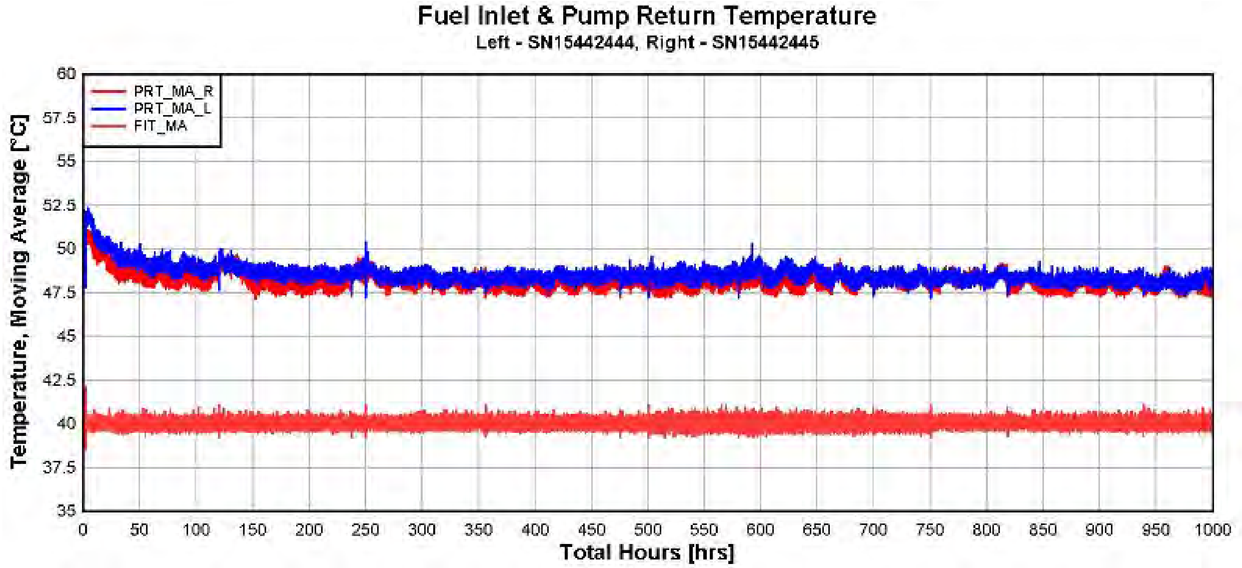


Figure S-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table S-3. (Note – Calibration data to be used as reference only)

Table S-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 19			Test Duration : 1000-hrs.		
Test Fuel :	FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 105°F			SN : 15442444			SN : 15442445		
PUMP RPM	Description	Specification		Pump Duration : 1000.-hrs.			Pump Duration : 1000.-hrs.		
		Min	Max	Before	After	Change	Before	After	Change
1000	Transfer pump psi.	60 psi	62 psi	62 psi	61 psi	1 psi	62 psi	**63 psi**	-1 psi
	Return Fuel	225 cc	375 cc	325 cc	340 cc	-15 cc	350 cc	334 cc	16 cc
350	Low Idle	12 cc	16 cc	16.0 cc	**11.5 cc**	4.5 cc	14.0 cc	**11.0 cc**	3.0 cc
	Housing psi.	8 psi	12 psi	11.0 psi	11.0 psi	.0 psi	9.0 psi	10.0 psi	-1.0 psi
	Advance	3.50°		4.40°	4.37°	.03°	**3.01°**	**2.76°**	.25°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	67.0 cc	1.0 cc	68.0 cc	**66.0 cc**	2.0 cc
1600	WOT Fuel delivery	60 cc		65 cc	63 cc	2 cc	63 cc	60 cc	3 cc
	WOT Advance	2.50°	3.50°	3.03°	3.50°	-.47°	3.01°	3.16°	-.15°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	22.0 cc	.0 cc	22.0 cc	22.0 cc	.0 cc
	Face Cam Advance	5.25°	7.25°	6.92°	6.98°	-.06°	5.83°	5.97°	-.14°
	Low Idle	11.0°	12.0°	**10.9°**	**10.9°**	-.1°	**10.8°**	**10.8°**	.0°
1825	Fuel Delivery	33 cc		39 cc	58 cc	-19 cc	40 cc	59 cc	-19 cc
1950	High Idle		15 cc	2 cc	**61 cc**	-59 cc	2 cc	15 cc	-13 cc
	Transfer pump psi.		125 psi	106 psi	92 psi	14 psi	109 psi	105 psi	4 psi
200	WOT Fuel Delivery	58 cc		60 cc	60 cc	0 cc	62 cc	59 cc	3 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		50 cc	50 cc	cc	51 cc	45 cc	6 cc
	Transfer pump psi.	16 psi		22 psi	21 psi	1 psi	30 psi	29 psi	1 psi
	Housing psi.	.0 psi	12 psi	10.0 psi	10 psi	0 psi	10 psi	9 psi	1 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table S-4 and Table S-5.

Table S-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15442444	Test Number: 19	
Fuel Description : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 105°F				
	Date:	1/0/1900	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000.-hrs.***	***Change***
Measurement 1	Mass (g)	3.2852	3.2744	-0.0108
Measurement 2		3.2853	3.2745	-0.0108
Measurement 3		3.2853	3.2746	-0.0107
Measurement 4		3.2854	3.2745	-0.0109
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2854	3.2767	-0.0087
Measurement 2		3.2853	3.2768	-0.0085
Measurement 3		3.2854	3.2769	-0.0085
Measurement 4		3.2853	3.2769	-0.0084
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2101	3.2073	-0.0028
Measurement 2		3.2100	3.2074	-0.0026
Measurement 3		3.2101	3.2072	-0.0029
Measurement 4		3.2100	3.2073	-0.0027
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2721	3.2628	-0.0093
Measurement 2		3.2722	3.2627	-0.0095
Measurement 3		3.2722	3.2628	-0.0094
Measurement 4		3.2722	3.2627	-0.0095
Average Measurements		***0-hrs.***	***1000.-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2853	3.2745	-0.0108
Transfer Pump Blade 2		3.2854	3.2768	-0.0085
Transfer Pump Blade 3		3.2101	3.2073	-0.0027
Transfer Pump Blade 4		3.2722	3.2628	-0.0094
	Roller to Roller (in)	1.9760	1.9760	0.0000
	Eccentricity (in.)	0.0070	0.0090	0.0020
	Drive Backlash (In)	0.0030	0.0080	0.0050

Table S-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15442445	Test Number: 19	
Fuel Description : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 105°F				
	Date:	1/0/1900	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.1803	3.1869	0.0066
Measurement 2		3.1801	3.1870	0.0069
Measurement 3		3.1801	3.1868	0.0067
Measurement 4		3.1802	3.1870	0.0068
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2210	3.2156	-0.0054
Measurement 2		3.2208	3.2156	-0.0052
Measurement 3		3.2209	3.2157	-0.0052
Measurement 4		3.2208	3.2156	-0.0052
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2418	3.2365	-0.0053
Measurement 2		3.2418	3.2364	-0.0054
Measurement 3		3.2417	3.2364	-0.0053
Measurement 4		3.2418	3.2364	-0.0054
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2058	3.2097	0.0039
Measurement 2		3.2057	3.2099	0.0042
Measurement 3		3.2058	3.2098	0.0040
Measurement 4		3.2057	3.2097	0.0040
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.1802	3.1869	0.0067
Transfer Pump Blade 2		3.2209	3.2156	-0.0053
Transfer Pump Blade 3		3.2418	3.2364	-0.0053
Transfer Pump Blade 4		3.2058	3.2098	0.0040
	Roller to Roller (in)	1.9760	1.9761	0.0001
	Eccentricity (in.)	0.0070	0.0060	-0.0010
	Drive Backlash (In)	0.0060	0.0100	0.0040

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table S-6.

Table S-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection												
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
19	15442444	FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 105°F	19-1	2125	1600	Pass	Pass	Pass	Pass	Pass	Pass
			19-2	2100	1600	Pass	Pass	Pass	Pass	Pass	Pass
			19-3	2100	1450	Pass	Fail	Pass	Pass	Pass	Pass
			19-4	2150	1550	Pass	Pass	Pass	Pass	Pass	Pass
			19-5	2150	1600	Pass	Pass	Pass	Pass	Pass	Pass
			19-6	2150	1600	Pass	Pass	Pass	Pass	Pass	Pass
			19-7	2125	1600	Pass	Pass	Pass	Pass	Pass	Pass
			19-8	2150	1625	Pass	Pass	Pass	Pass	Pass	Pass
19	15442445	FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 105°F	19-11	2125	1550	Pass	Fail	Pass	Pass	Pass	Pass
			19-12	2125	1650	Pass	Pass	Pass	Pass	Pass	Pass
			19-13	2125	1500	Pass	Fail	Pass	Pass	Pass	Pass
			19-14	2125	1500	Pass	Fail	Pass	Pass	Pass	Pass
			19-15	2125	1600	Pass	Pass	Pass	Pass	Pass	Pass
			19-16	2100	1475	Pass	Fail	Pass	Pass	Pass	Pass
			19-17	2125	1525	Pass	Fail	Pass	Pass	Pass	Pass
			19-18	2150	1475	Pass	Fail	Pass	Pass	Pass	Pass
			Passed 9 out of 16								

Comments : ______________________________

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table S-7 and Table S-8.

Table S-7. Stanadyne Left Pump Parts Evaluation

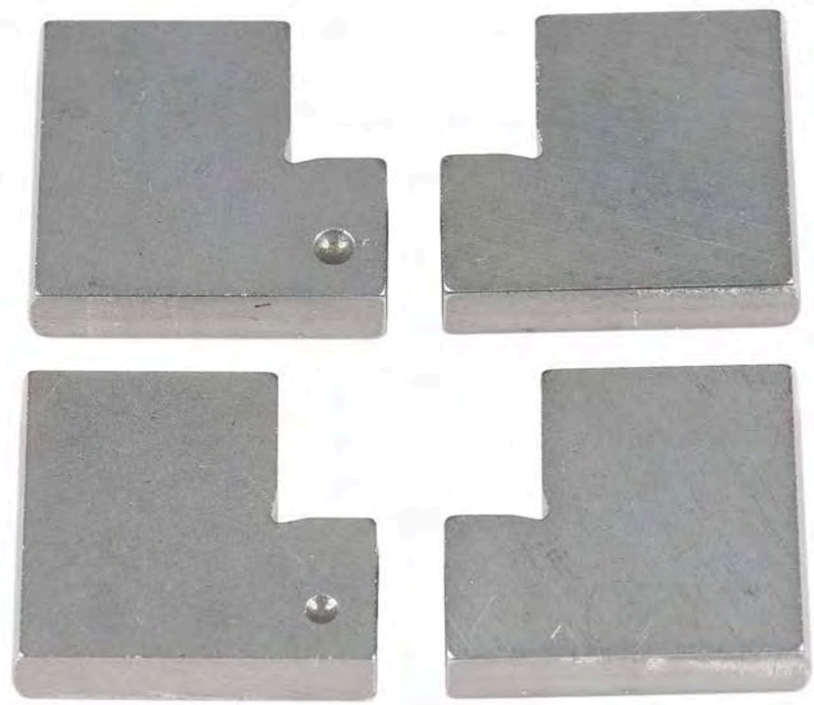
Pump Type : DB2831-5079		SN: 15442444
Test Condition : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 105°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	3
BLADE SPRINGS	Rubbing wear	1.5
LINER	90% Wear	3.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	2
REGULATOR PISTON	Polishing wear	1
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	2.5
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Polishing wear and light scratces	1.5
SHOES	Dimple, light waer from leaf spring contact	2
ROLLERS	Light radial scratches	1.5
LEAF SPRING	Polishing wear	2
CAM RING	Groove from weight contact	1
THRUST WASHER	Polishing wear from weight contact	1
THRUST SLEEVE	Normal, brown deposits	1
GOVORNER WEIGHTS	Wear from thrust washer contact	1.5
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Polishing wear. Light brown deposits	1.5
DRIVE SHAFT TANG	Fretting wear at rotor contact	2
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scoring wear	3
HOUSING	Light brown stain inside	1
	AVERAGE DEMERIT RATINGS	1.739

Table S-8. Stanadyne Right Pump Parts Evaluation

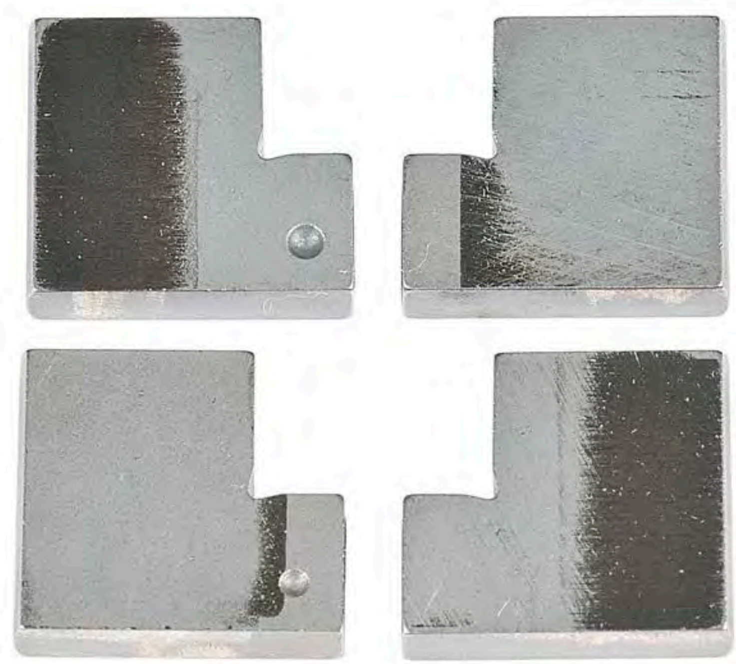
Pump Type : DB2831-5079	SN: 15442445
Test Condition : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 105°F	Pump Duration : 1000.-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Wear at rotor slots and liner contact	3.5
BLADE SPRINGS	Rubbing wear	1.5
LINER	90% Wear	3.5
TRANSFER PUMP REGULATOR	Wear mark from rotor, light polishing	2
REGULATOR PISTON	Scuffing wear	3
ROTOR	Wear at distributor ports	2.5
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Polishing wear	2.5
PLUNGERS	Polishing wear and light scratces	1.5
SHOES	Dimple, light waer from leaf spring contact	2
ROLLERS	Light radial scratches	2
LEAF SPRING	Polishing wear	1.5
CAM RING	Groove from weight contact	1
THRUST WASHER	Polishing wear from weight contact	1
THRUST SLEEVE	Normal, brown deposits	1
GOVORNER WEIGHTS	Wear from thrust washer contact	1.5
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Polishing wear. Light brown deposits	1.5
DRIVE SHAFT TANG	Polishing wear	1
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal	1
ADVANCE PISTON	Scoring wear	2.5
HOUSING	Light brown stain inside	1
	AVERAGE DEMERIT RATINGS	1.804

PHOTOGRAPHS FOR LEFT PUMP



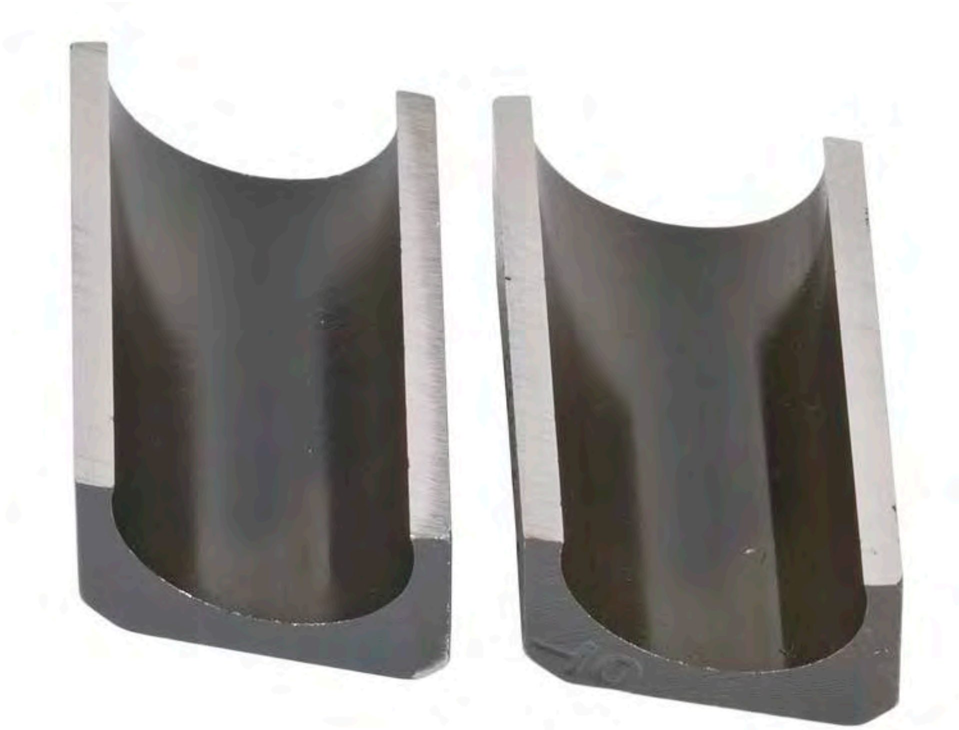
SN15242444 Transfer Pump Blades (Side), Before



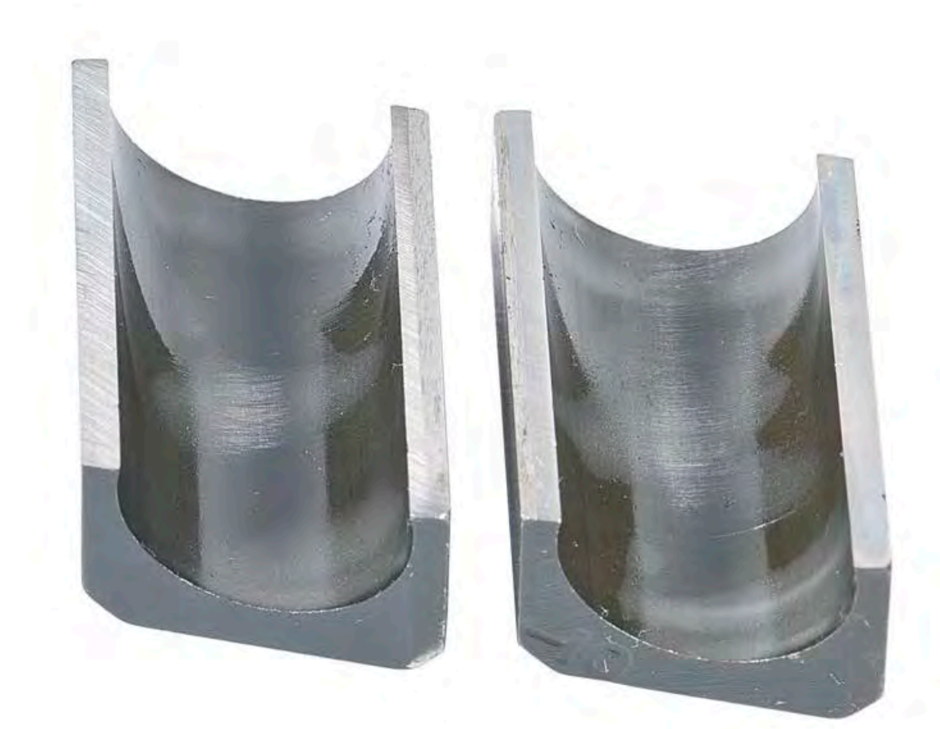
SN15242444 Transfer Pump Blades (Side), After

SN15442444 Transfer Pump Blades (Profile), Before

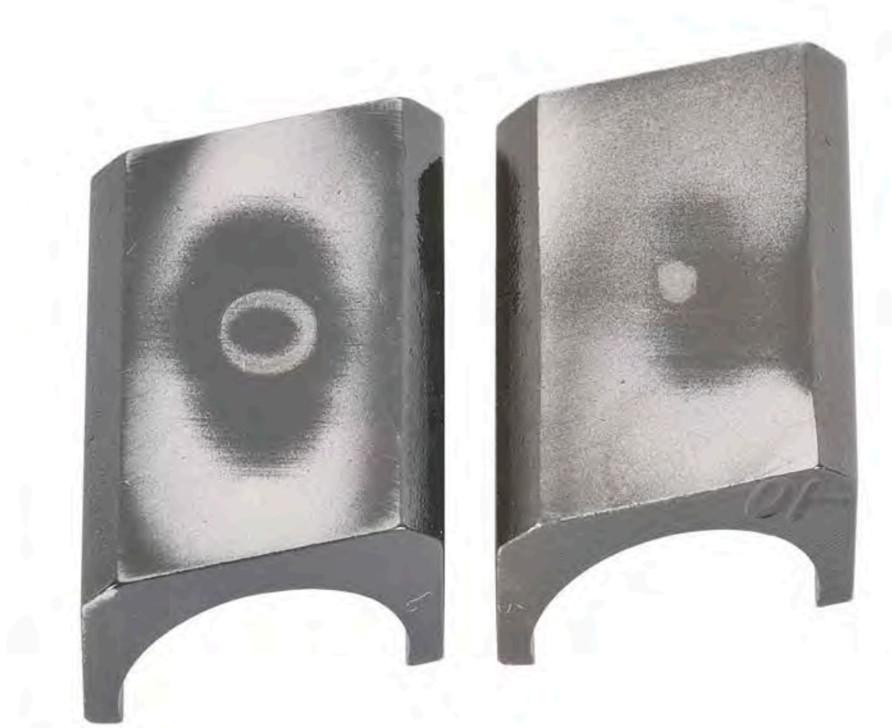
SN15442444 Transfer Pump Blades (Profile), After



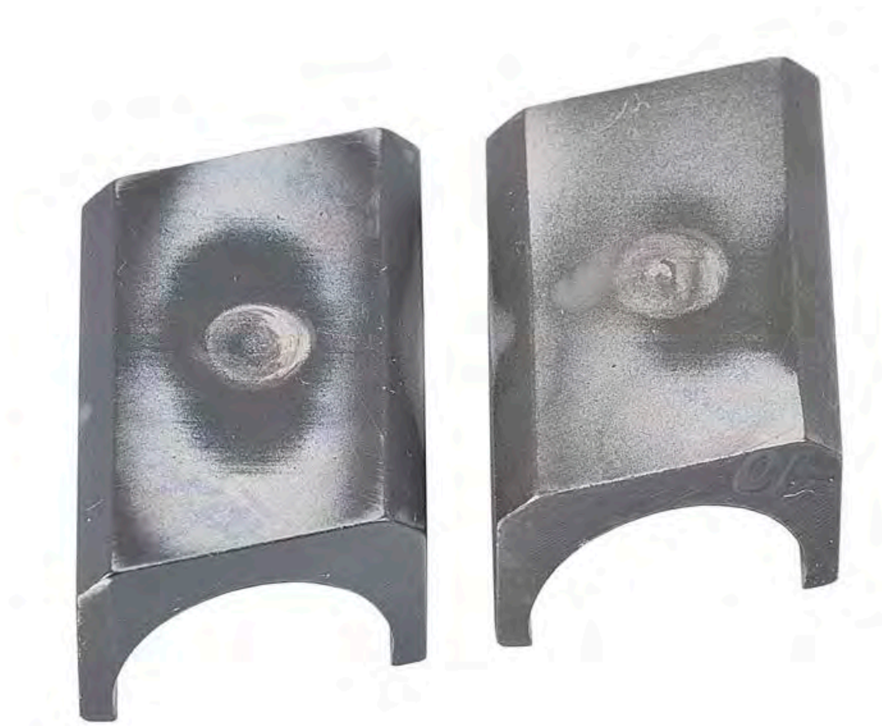
SN15442444 Shoes (Front), Before



SN15442444 Shoes (Front), After



SN15442444 Shoes (Back), Before



SN15442444 Shoes (Back), After

SN15442444 Rollers, Before

SN15442444 Rollers, After

SN15442444 Piston Plungers, Before

SN15442444 Piston Plungers, After

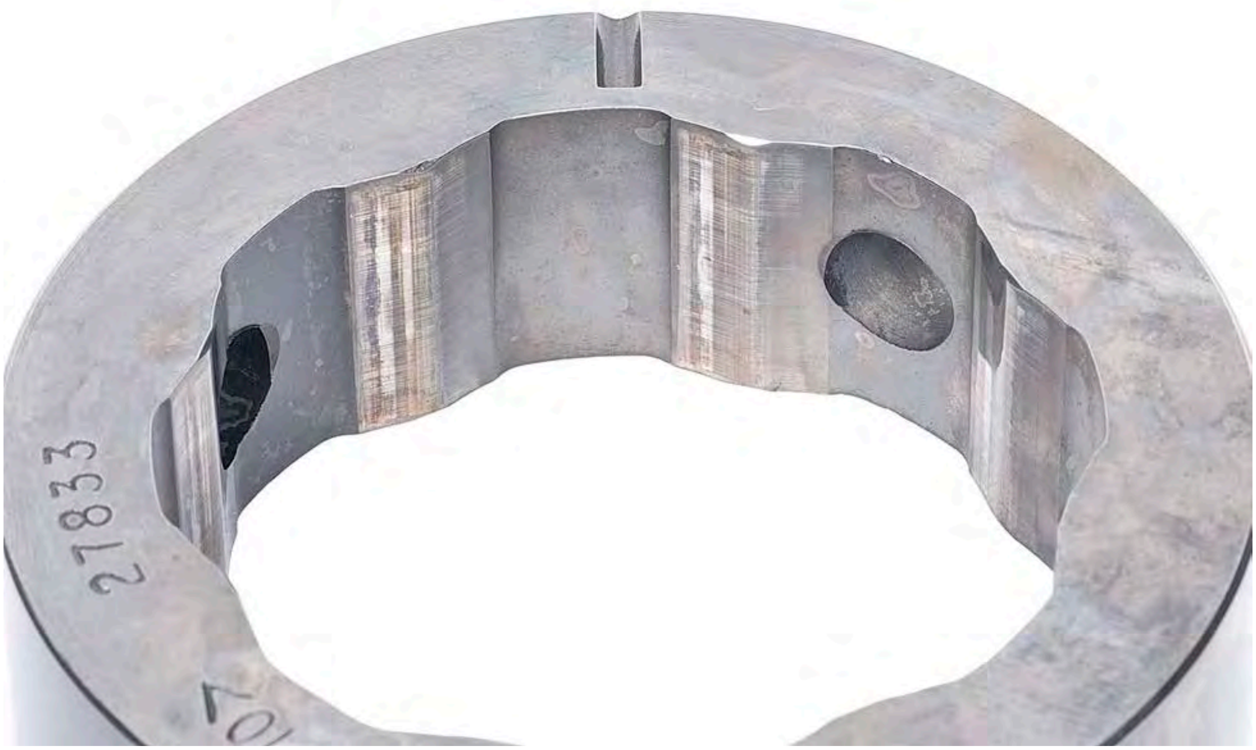
SN15442444 Thrust Washer, Before

SN15442444 Thrust Washer, After

SN15442444 Governor Weight, Before

SN15442444 Governor Weight, After

SN15442444 Cam Ring, Before



SN15442444 Cam Ring, After

SN15442444 Eccentric Ring, Before

SN15442444 Eccentric Ring, After

SN15442444 Rotor (Front), Before

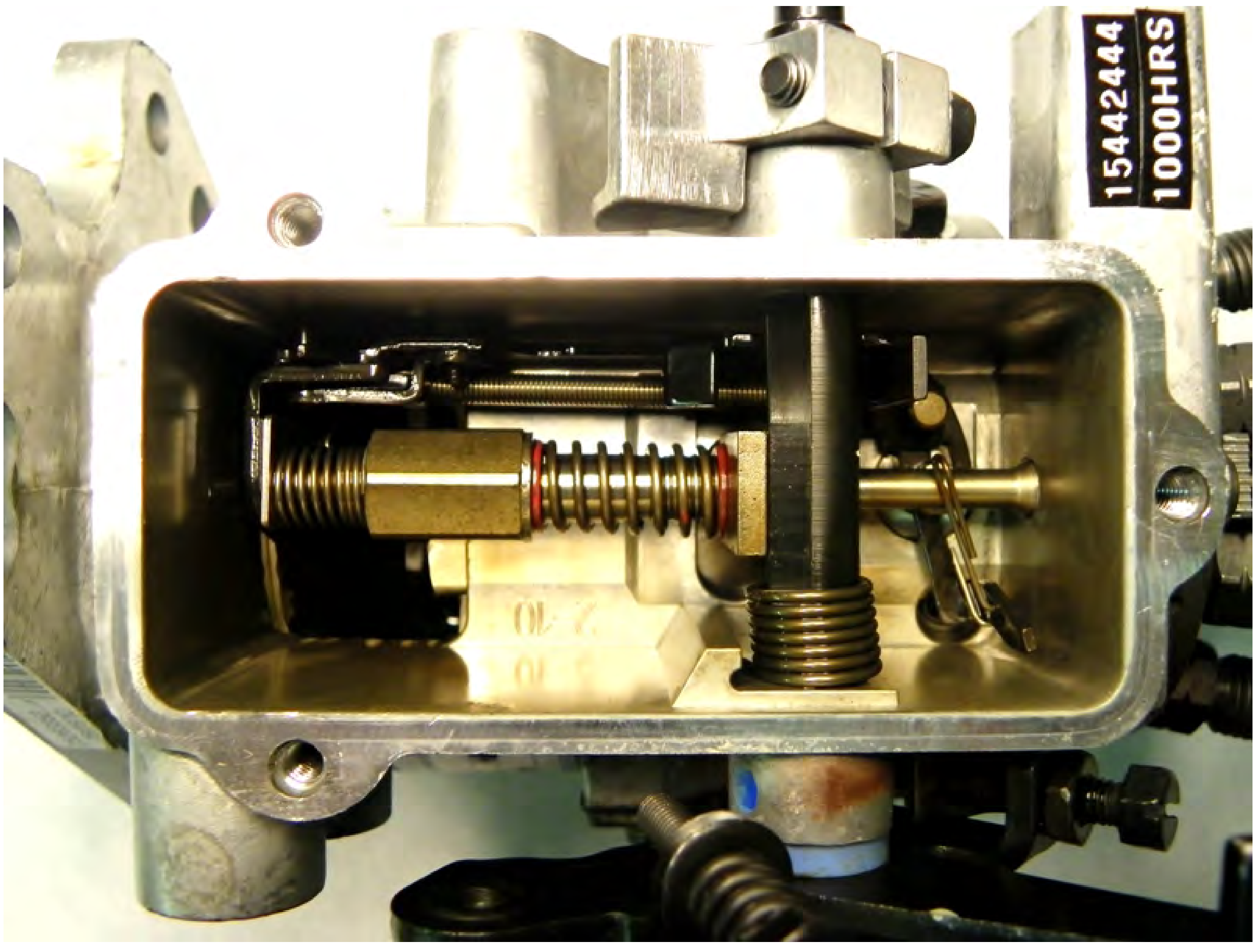
SN15442444 Rotor (Front), After

SN15442444 Rotor (Back), Before

SN15442444 Rotor (Back), After

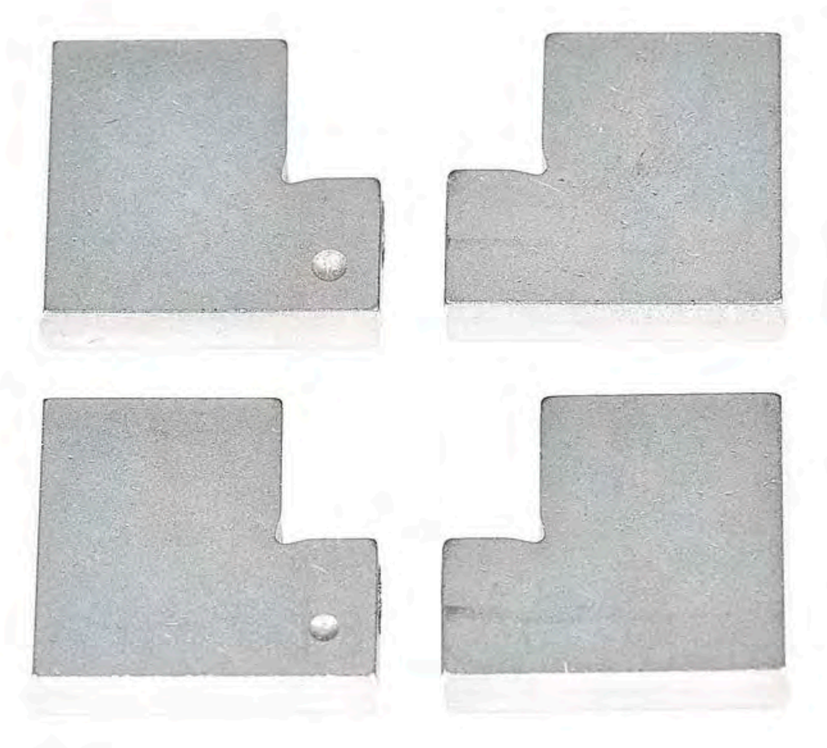
SN15442444 Drive Tang, Before

SN15442444 Drive Tang, After

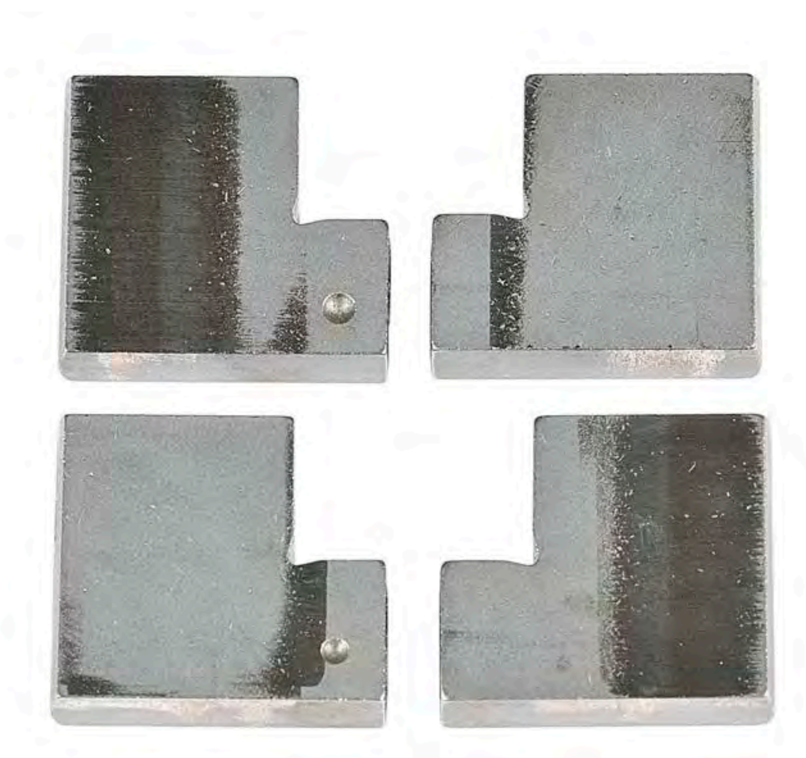


SN15442444 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



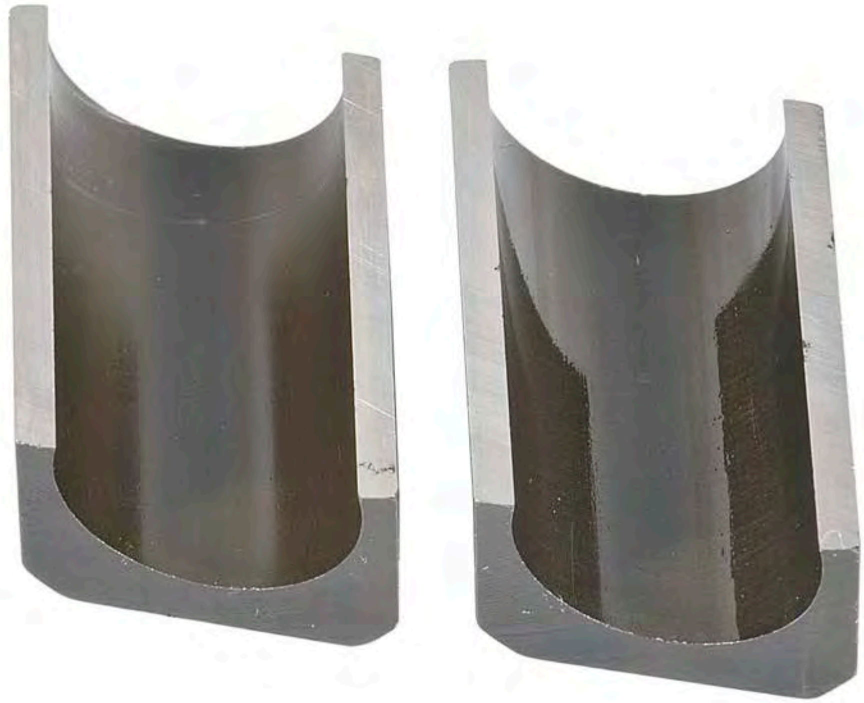
SN15442445 Transfer Pump Blades, Before



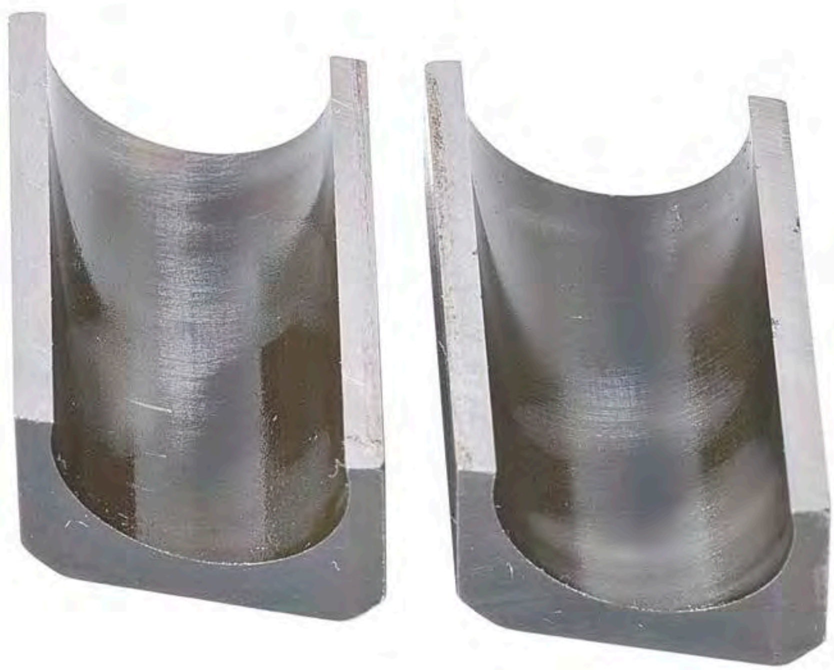
SN15442445 Transfer Pump Blades, After

SN15442445 Transfer Pump Blades (Profile), Before

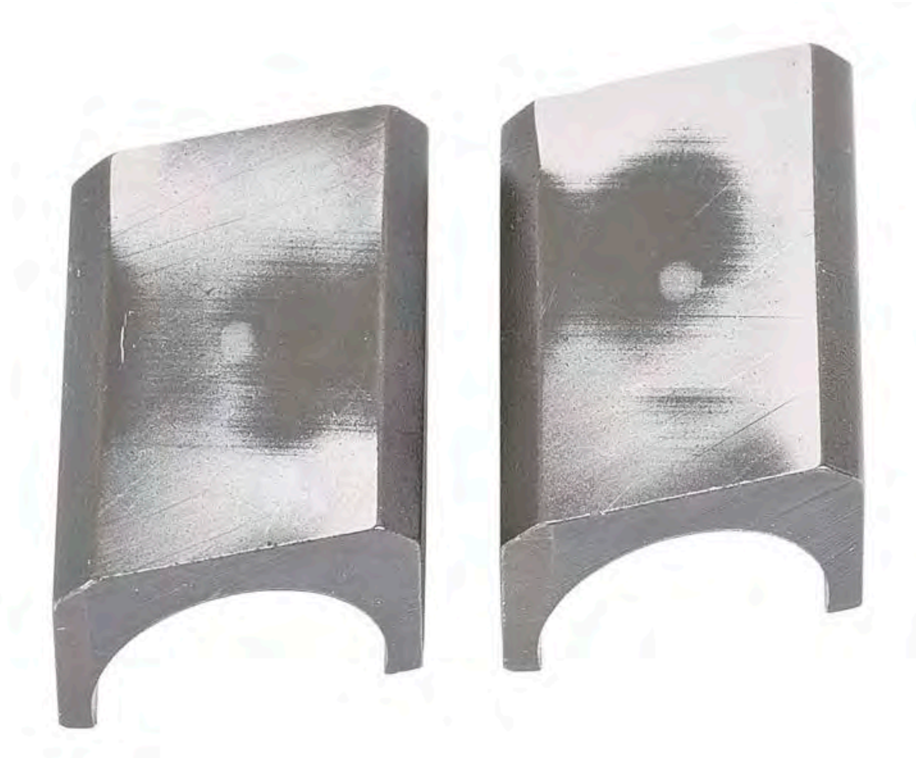
SN15442445 Transfer Pump Blades (Profile), After



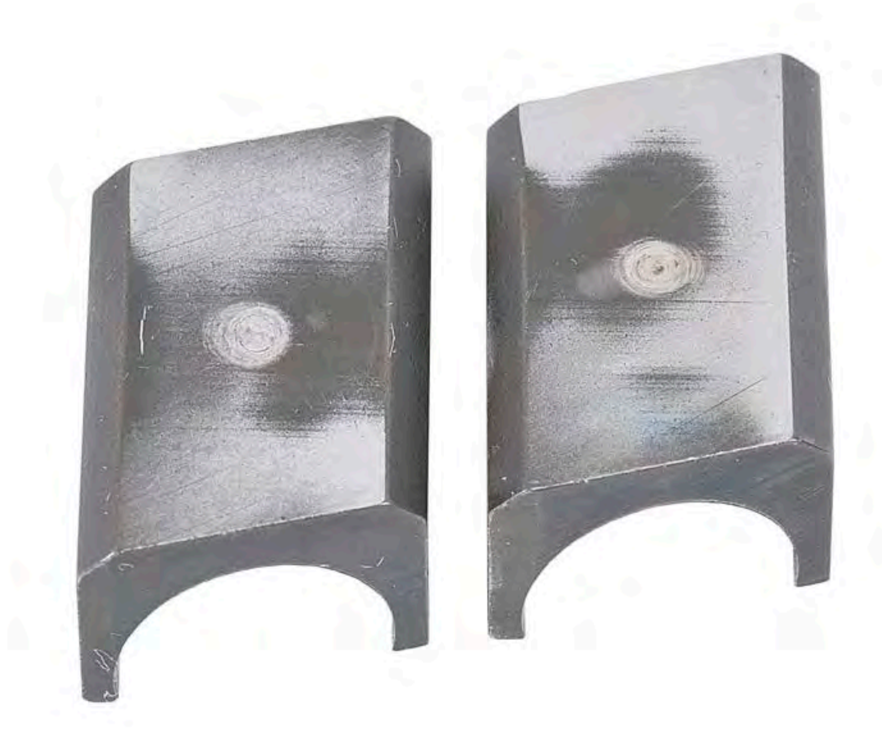
SN15442445 Shoes (Front), Before



SN15442445 Shoes (Front), After



SN15442445 Shoes (Back), Before



SN15442445 Shoes (Back), After

SN15442445 Rollers, Before

SN15442445 Rollers, After

SN15442445 Piston Plungers, Before

SN15442445 Piston Plungers, After

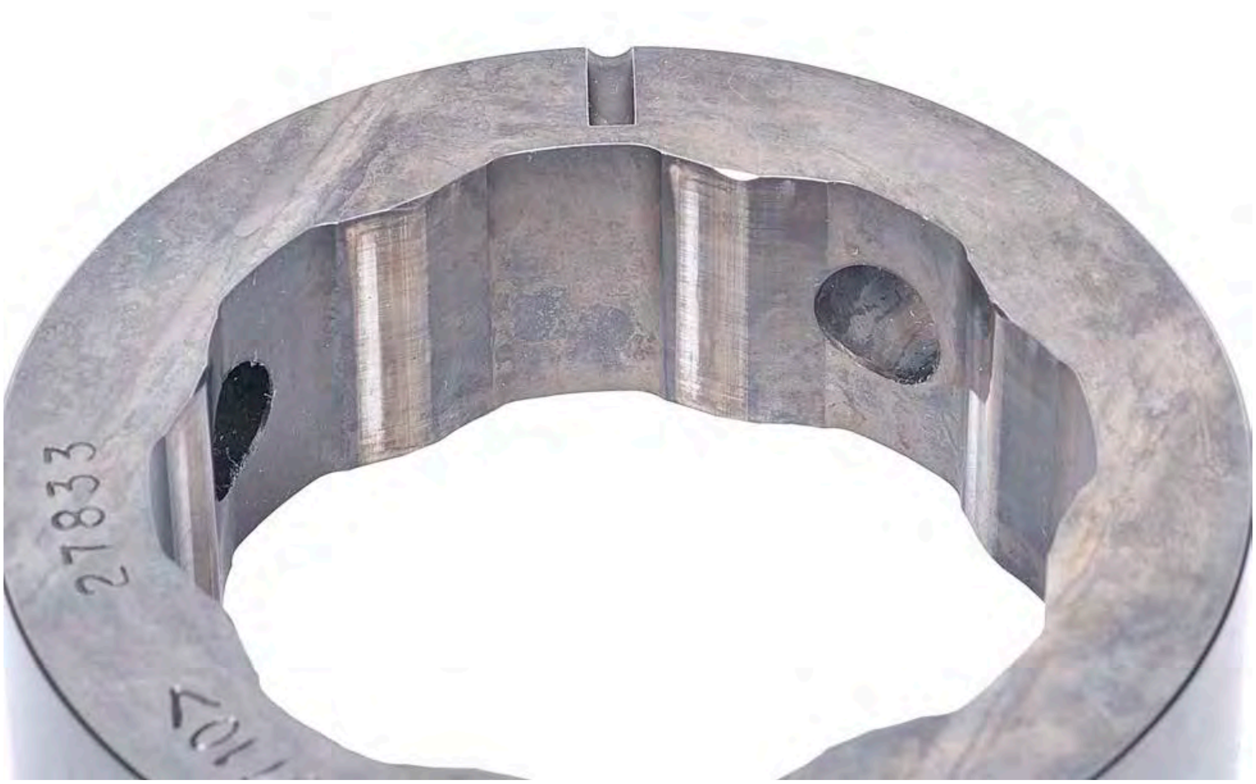
SN15442445 Thrust Washer, Before

SN15442445 Thrust Washer, After

SN15442445 Governor Weight, Before

SN15442445 Governor Weight, After

SN15442445 Cam Ring, Before



SN15442445 Cam Ring, After

SN15442445 Eccentric Ring, Before

SN15442445 Eccentric Ring, After

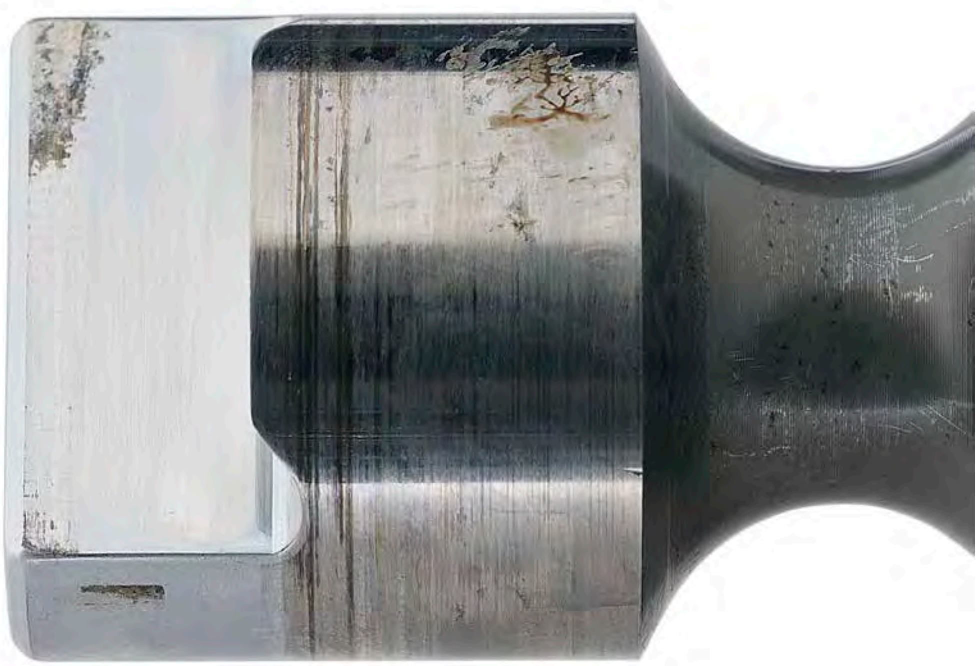
SN15442445 Rotor (Front), Before

SN15442445 Rotor (Front), After

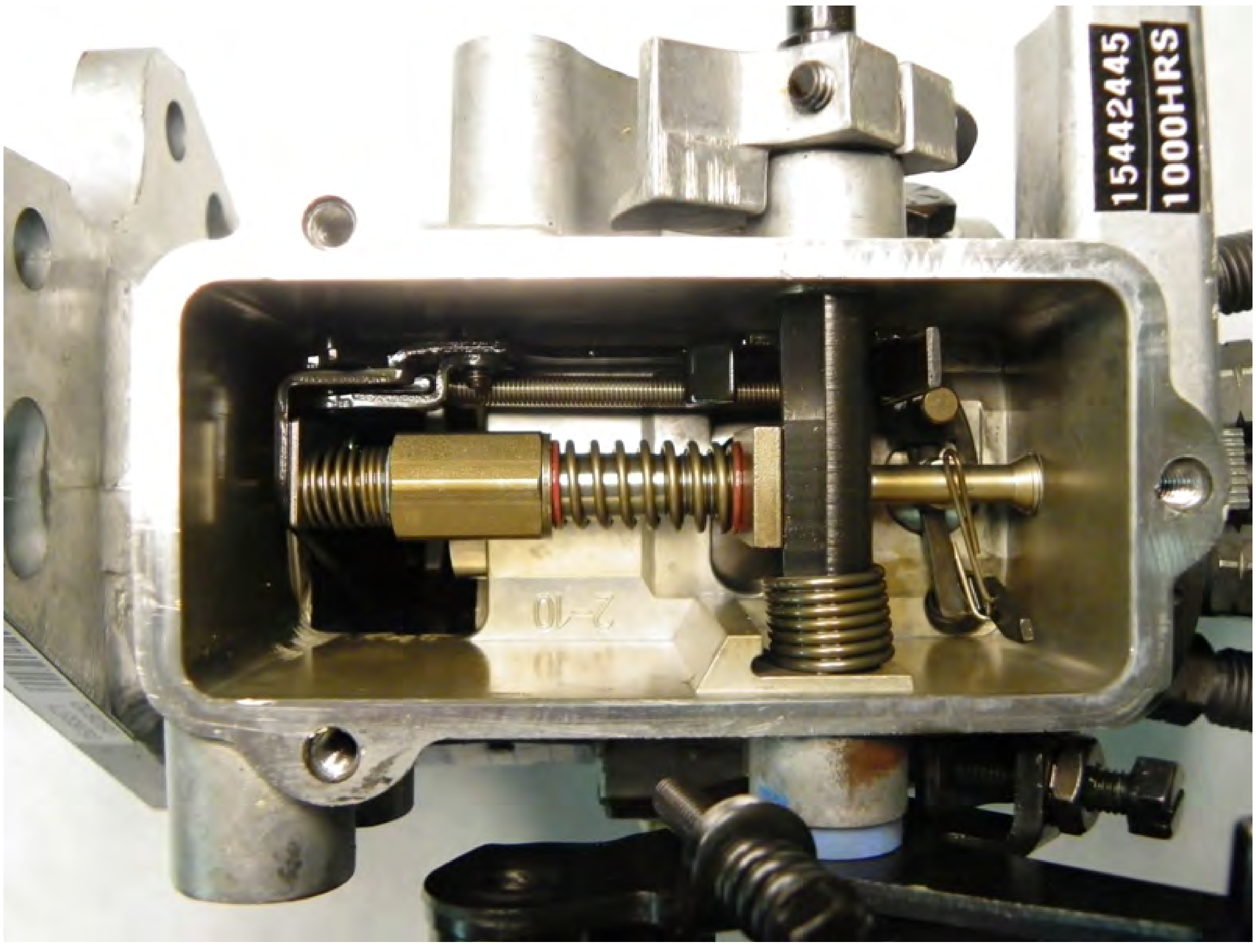
SN15442445 Rotor (Back), Before

SN15442445 Rotor (Back), After

SN15442445 Drive Tang, Before



SN15442445 Drive Tang, After



SN15442445 Governor Assembly

APPENDIX T

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: FT-SPK/Jet A-1 with 9-mg/L DCI-4A
Test Number: FTJA9-C4T20-57-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: FT-SPK/Jet A-1 with 9-mg/L DCI-4A

Test Fuel ID: AF7090

Test Temperature: 57°C (135°F)

Test Number: FTJA9-C4T20-57-1000

Start of Test Date: April 26, 2011

End of Test Date: June 27, 2012

Test Duration: 1,000 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure T-1.

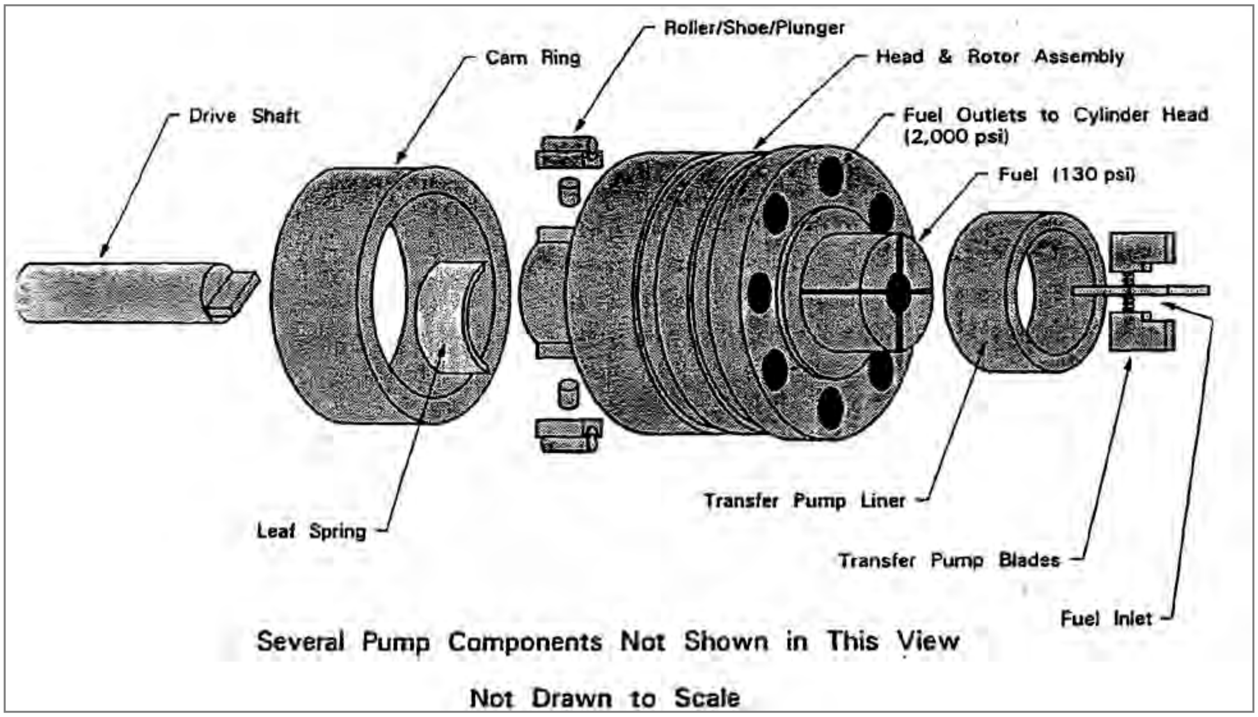


Figure T-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table T-1.

Table T-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	57 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table T-2.

Table T-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1701	2.7299
FLO_R	Injeted Flowrate [mL/min]	669.4	29.1
FUELIN_P	Fuel Inlet Pressure [psig]	3	0.474
TRNS_P_R	Transfer Pump Pressure [psig]	73	.8834
HSG_P_R	Pump Housing Pressure [psig]	15.8	0.98
RTRN_T_R	Fuel Return Temperature [°C]	63.4	.64
FUEL_T	Fuel Tank Temperature [°C]	27.9	1.9
FUELIN_T	Fuel Inlet Temperature [°C]	57	0.15

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure T-2 through Figure T-4.

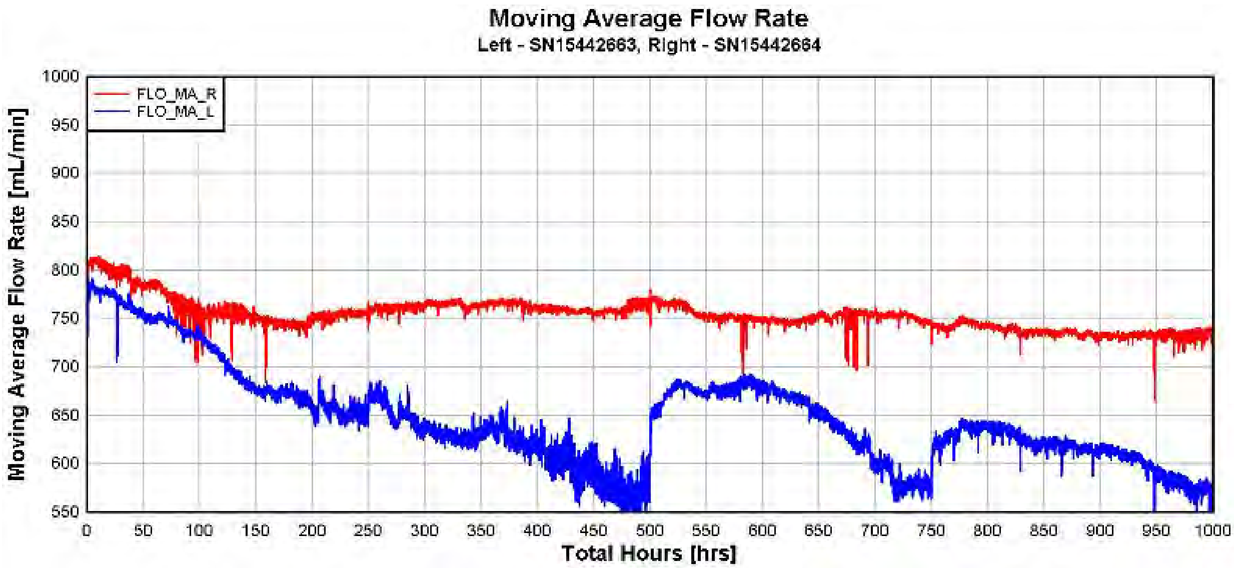


Figure T-2. Pump Flow, Moving Average

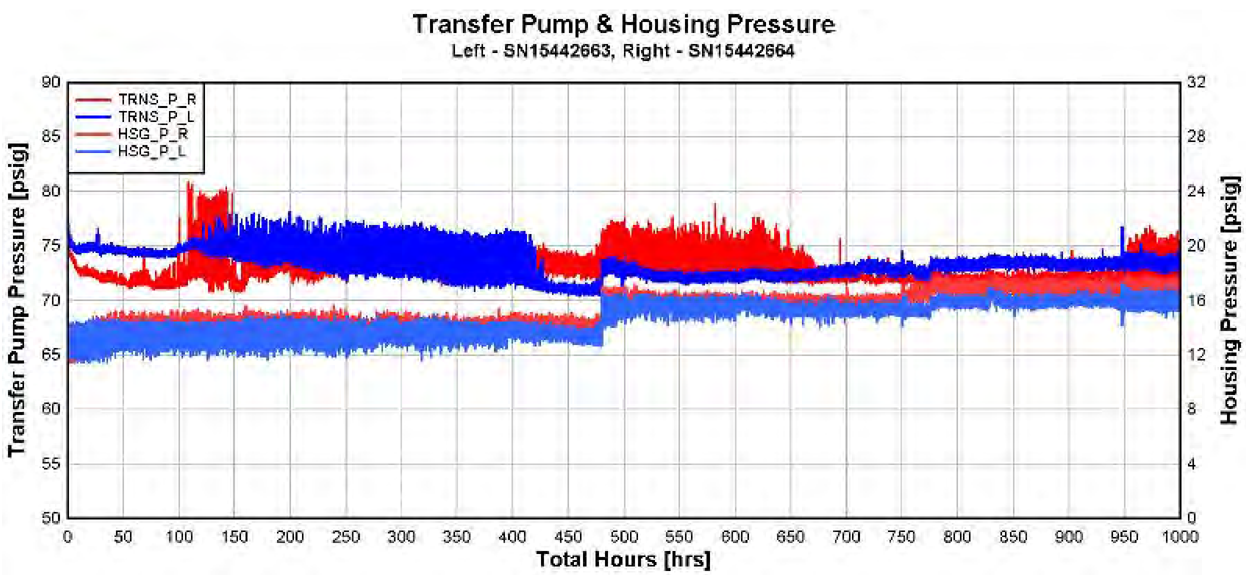


Figure T-3. Transfer Pump & Housing Pressure

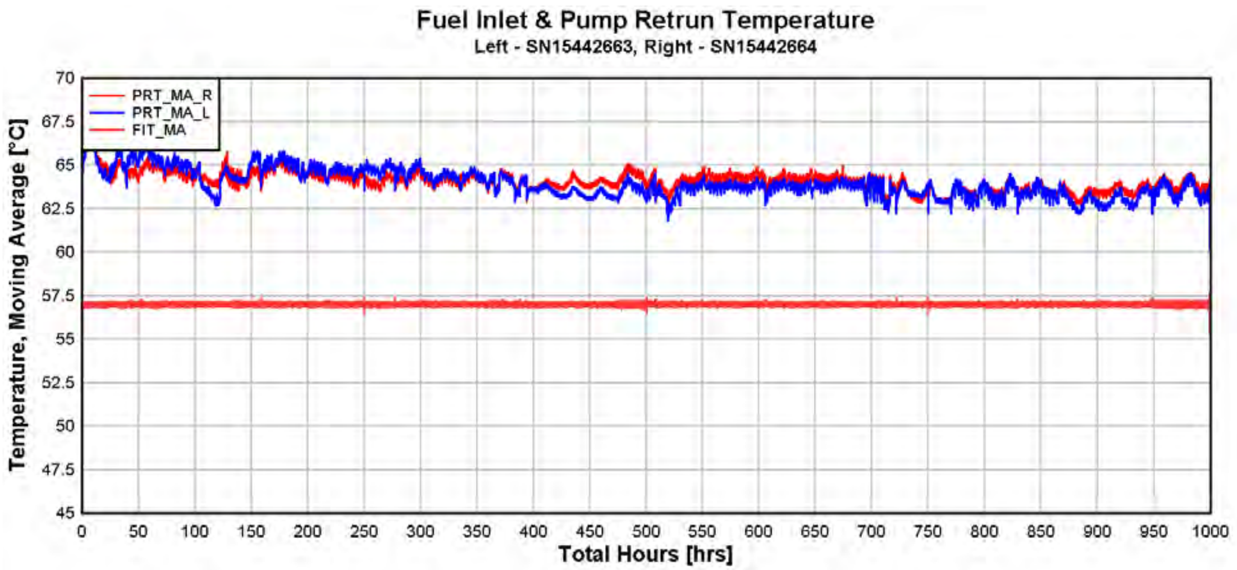


Figure T-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table T-3. (Note – Calibration data to be used as reference only)

Table T-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 20			Test Duration : 1000-hrs.		
Test Fuel :	FT-SPK /Jet A-1 w/9-mg/L DCI-4A @ 135°F			SN : 15442663			SN : 15442664		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 1000.-hrs.*			*Pump Duration : 1000.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	62 psi	psi	62 psi	61 psi	1 psi
	Return Fuel	225 cc	375 cc	348 cc	330 cc	18 cc	300 cc	312 cc	-12 cc
350	Low Idle	12 cc	16 cc	15 cc	**46 cc**	-31 cc	14 cc	**24 cc**	-10 cc
	Housing psi.	8 psi	12 psi	10.0 psi	9.0 psi	1.0 psi	10.0 psi	9.5 psi	.5 psi
	Advance	3.50°		4.60°	**1.70°**	2.90°	**3.40°**	**3.07°**	.33°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.5 psi	-.5 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	68.0 cc	.0 cc	68.0 cc	**66.0 cc**	2.0 cc
1600	WOT Fuel delivery	60 cc		66 cc	**44 cc**	22 cc	65 cc	**53 cc**	12 cc
	WOT Advance	2.50°	3.50°	2.98°	**3.69°**	-.71°	3.00°	**3.95°**	-.95°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	**21.0 cc**	1.0 cc	22.0 cc	23.0 cc	-1.0 cc
	Face Cam Advance	5.25°	7.25°	6.89°	**8.17°**	-1.28°	6.21°	6.79°	-.58°
	Low Idle	11.0°	12.0°	11.0°	11.1°	-.1°	11.2°	11.6°	-.4°
1825	Fuel Delivery	33 cc		37 cc	40 cc	-3 cc	40 cc	50 cc	-10 cc
1950	High Idle		15 cc	2 cc	2 cc	cc	1 cc	2 cc	-1 cc
	Transfer pump psi.		125 psi	107 psi	105 psi	2 psi	109 psi	112 psi	-3 psi
200	WOT Fuel Delivery	58 cc		63 cc	58 cc	5 cc	63 cc	58 cc	5 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		52 cc	45 cc	7 cc	49 cc	43 cc	6 cc
	Transfer pump psi.	16 psi		28 psi	27 psi	1 psi	26 psi	25 psi	1 psi
	Housing psi.	.0 psi	12 psi	10.0 psi	8 psi	2 psi	9 psi	9 psi	0 psi
	Air Timing	-1.00°	.00°	-.50°	-.50°	.00°	-.50°	-.50°	.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table T-4 and Table T-5.

Table T-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15442663	Test Number: 20	
Fuel Description : FT-SPK /Jet A-1 w/9-mg/L DCI-4A @ 135°F				
	Date:	1/0/1900	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000.-hrs.***	***Change***
Measurement 1	Mass (g)	3.2391	3.2391	0.0000
Measurement 2		3.2390	3.2392	0.0002
Measurement 3		3.2390	3.2392	0.0002
Measurement 4		3.2390	3.2392	0.0002
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2205	3.2223	0.0018
Measurement 2		3.2202	3.2225	0.0023
Measurement 3		3.2203	3.2224	0.0021
Measurement 4		3.2203	3.2225	0.0022
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2320	3.2342	0.0022
Measurement 2		3.2319	3.2341	0.0022
Measurement 3		3.2320	3.2340	0.0020
Measurement 4		3.2321	3.2341	0.0020
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2211	3.2209	-0.0002
Measurement 2		3.2209	3.2209	0.0000
Measurement 3		3.2209	3.2210	0.0001
Measurement 4		3.2210	3.2205	-0.0005
Average Measurements		***0-hrs.***	***1000.-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2390	3.2392	0.0002
Transfer Pump Blade 2		3.2203	3.2224	0.0021
Transfer Pump Blade 3		3.2320	3.2341	0.0021
Transfer Pump Blade 4		3.2210	3.2208	-0.0002
	Roller to Roller (in)	1.9760	1.9760	0.0000
	Eccentricity (in.)	0.0080	0.0070	-0.0010
	Drive Backlash (In)	0.0060	0.0100	0.0040

Table T-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15442664	Test Number: 20	
Fuel Description : FT-SPK /Jet A-1 w/9-mg/L DCI-4A @ 135°F				
	Date:	1/0/1900	1/0/1900	
Transfer Pump Blade 1		***0-hrs.***	***1000-hrs.***	***Change***
Measurement 1	Mass (g)	3.2415	3.2402	-0.0013
Measurement 2		3.2414	3.2402	-0.0012
Measurement 3		3.2414	3.2401	-0.0013
Measurement 4		3.2415	3.2402	-0.0013
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2177	3.2165	-0.0012
Measurement 2		3.2178	3.2166	-0.0012
Measurement 3		3.2176	3.2167	-0.0009
Measurement 4		3.2177	3.2167	-0.0010
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2379	3.2288	-0.0091
Measurement 2		3.2380	3.2289	-0.0091
Measurement 3		3.2379	3.2287	-0.0092
Measurement 4		3.2379	3.2288	-0.0091
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2571	3.2513	-0.0058
Measurement 2		3.2569	3.2514	-0.0055
Measurement 3		3.2570	3.2515	-0.0055
Measurement 4		3.2570	3.2515	-0.0055
Average Measurements		***0-hrs.***	***1000-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2415	3.2402	-0.0013
Transfer Pump Blade 2		3.2177	3.2166	-0.0011
Transfer Pump Blade 3		3.2379	3.2288	-0.0091
Transfer Pump Blade 4		3.2570	3.2514	-0.0056
	Roller to Roller (in)	1.9760	1.9759	-0.0001
	Eccentricity (in.)	0.0080	0.0090	0.0010
	Drive Backlash (In)	0.0060	0.0150	0.0090

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table T-6.

Table T-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection											
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
20	15442663	FT-SPK /Jet A-1 w/9-mg/L DCI-4A @ 135°F	20-1	2125	1675	Pass	Pass	Pass	Pass	Pass	Pass
			20-2	2200	1750	Pass	Pass	Pass	Pass	Pass	Pass
			20-3	2100	1600	Pass	Pass	Pass	Pass	Pass	Pass
			20-4	2125	1575	Pass	Pass	Pass	Pass	Pass	Pass
			20-5	2125	1625	Pass	Pass	Pass	Pass	Pass	Pass
			20-6	2125	1775	Pass	Pass	Pass	Pass	Pass	Pass
			20-7	2150	1750	Pass	Pass	Pass	Pass	Pass	Pass
			20-8	2125	1700	Pass	Pass	Pass	Pass	Pass	Pass
20	15442664	FT-SPK /Jet A-1 w/9-mg/L DCI-4A @ 135°F	20-11	2125	1675	Pass	Pass	Pass	Pass	Pass	Pass
			20-12	2175	1700	Pass	Pass	Pass	Pass	Pass	Pass
			20-13	2200	1775	Pass	Pass	Pass	Pass	Pass	Pass
			20-14	2150	1700	Pass	Pass	Pass	Pass	Pass	Pass
			20-15	2125	1700	Pass	Pass	Pass	Pass	Pass	Pass
			20-16	2150	1675	Pass	Pass	Pass	Pass	Pass	Pass
			20-17	2150	1725	Pass	Pass	Pass	Pass	Pass	Pass
			20-18	2100	1725	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments : ____________________

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table T-7 and Table T-8.

Table T-7. Stanadyne Left Pump Parts Evaluation

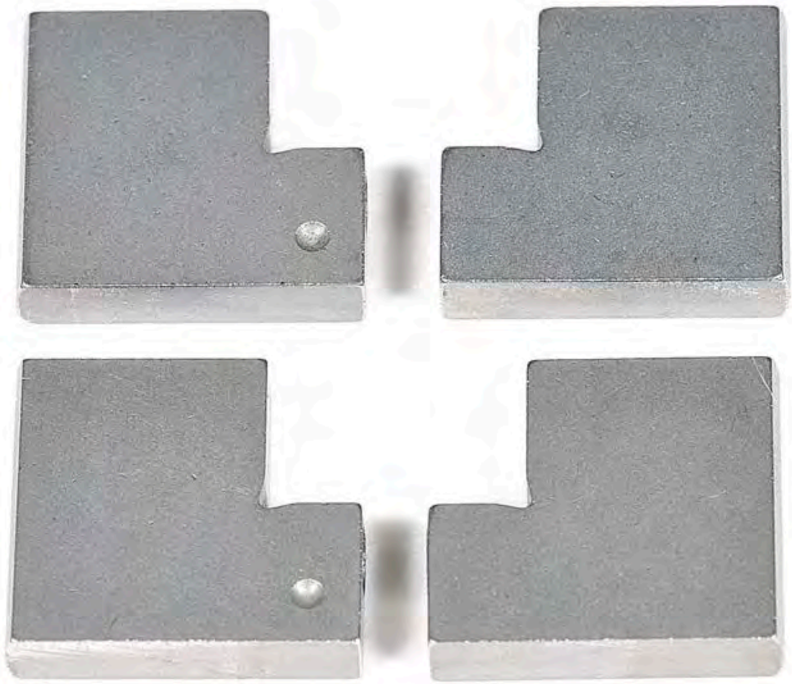
Pump Type : DB2831-5079		SN: 15442663
Test Condition : FT-SPK /Jet A-1 w/9-mg/L DCI-4A @ 135°F		Pump Duration : 1000.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing wear	1.5
LINER	80% Wear	4.5
TRANSFER PUMP REGULATOR	Waer mark from rotor, light polishing	2.5
REGULATOR PISTON	Polishing wear, light scuffing	2.5
ROTOR	Wear at distributor ports	2
ROTOR RETAINERS	Wear from rotor contact	2.5
DELIVERY VALVE	Polishing wear	2
PLUNGERS	Polishing wear and light scratces	1
SHOES	Dimple, light waer from leaf spring contact	2
ROLLERS	Light radial scrathes	2
LEAF SPRING	Wear from shoe contact	2
CAM RING	Polishing wear	1
THRUST WASHER	Polishing wear from weight contact	3
THRUST SLEEVE	Normal, brown stains	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2.5
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Spring loose ans worn through. Scuffing wear at helix	4
DRIVE SHAFT TANG	Polishing wear	2
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal. In spec	1
ADVANCE PISTON	Scorring wear	3
HOUSING	Light brown stain inside	1
	AVERAGE DEMERIT RATINGS	2.087

Table T-8. Stanadyne Right Pump Parts Evaluation

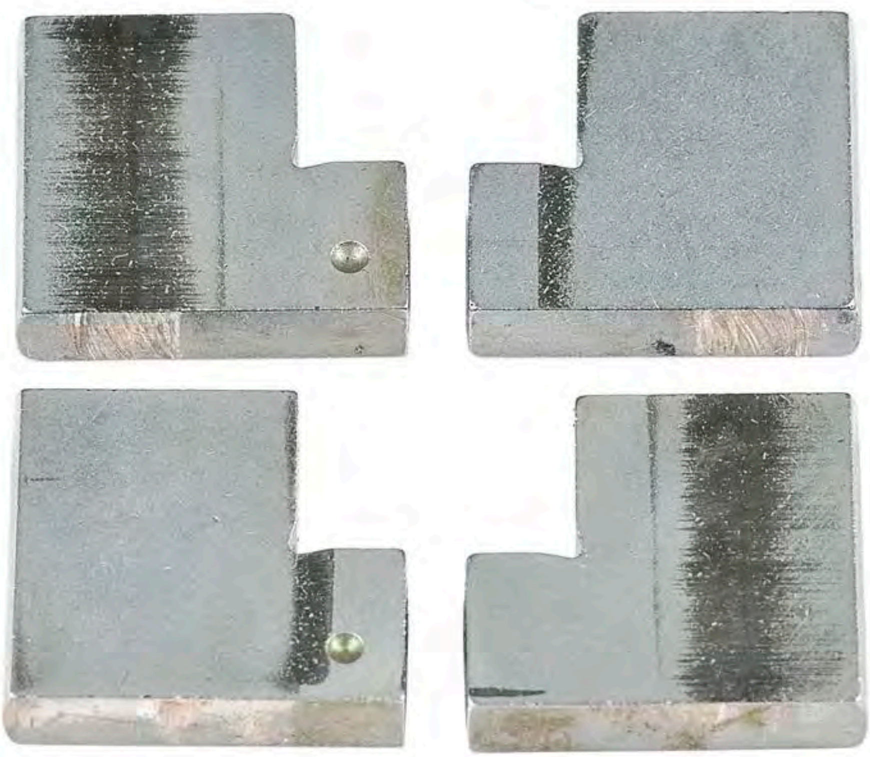
Pump Type : DB2831-5079	SN: 15442664
Test Condition : FT-SPK /Jet A-1 w/9-mg/L DCI-4A @ 135°F	Pump Duration : 1000.-hrs.

Part Name	Condition of Part	Rating 0 = New 5 = Failed
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing wear	2
LINER	75% Wear	4.5
TRANSFER PUMP REGULATOR	Waer mark from rotor, light polishing	2.5
REGULATOR PISTON	Polishing wear, light scuffing	2
ROTOR	Wear at distributor ports	2.5
ROTOR RETAINERS	Wear from rotor contact	2.5
DELIVERY VALVE	Polishing wear	2.5
PLUNGERS	Polishing wear.	2.5
SHOES	Dimple, light waer from leaf spring contact	2.5
ROLLERS	Light discoloration	1.5
LEAF SPRING	Wear from shoe contact	2
CAM RING	Polishing wear	1
THRUST WASHER	Polishing wear from weight contact	2
THRUST SLEEVE	Normal, brown stains	1
GOVORNER WEIGHTS	Wear from thrust washer contact	2.5
LINK HOOK	Dimple from governor rod	1.5
METERING VAVLE	Spring loose and almost worn through.	4
DRIVE SHAFT TANG	Fretting wear	2.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal. In spec	1
ADVANCE PISTON	Scorring wear	3
HOUSING	Light brown stain inside	1
	AVERAGE DEMERIT RATINGS	2.174

PHOTOGRAPHS FOR LEFT PUMP



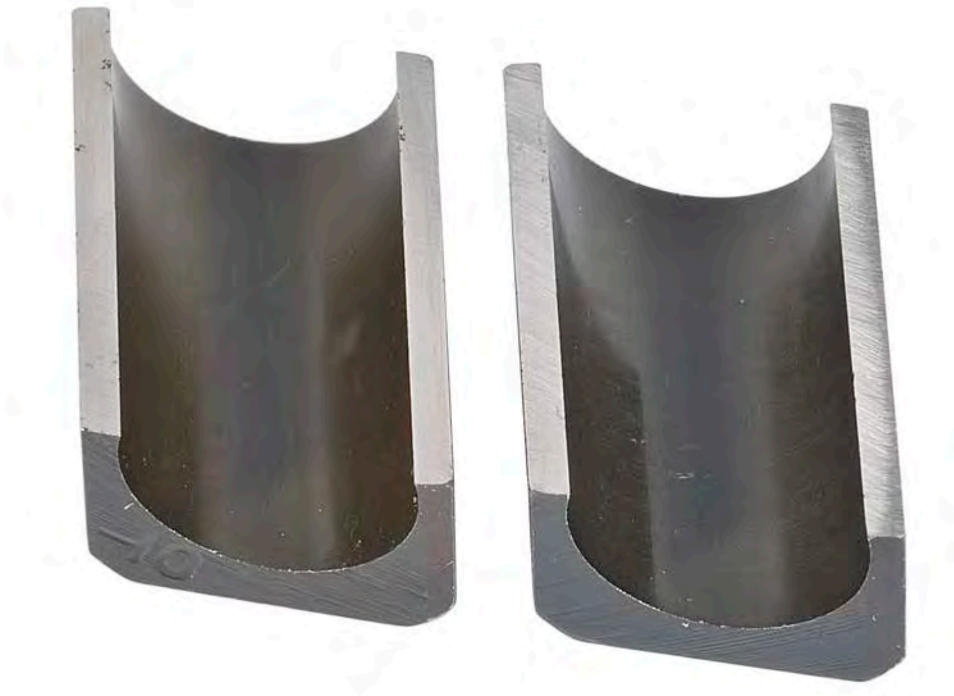
SN15442663 Transfer Pump Blades (Side), Before



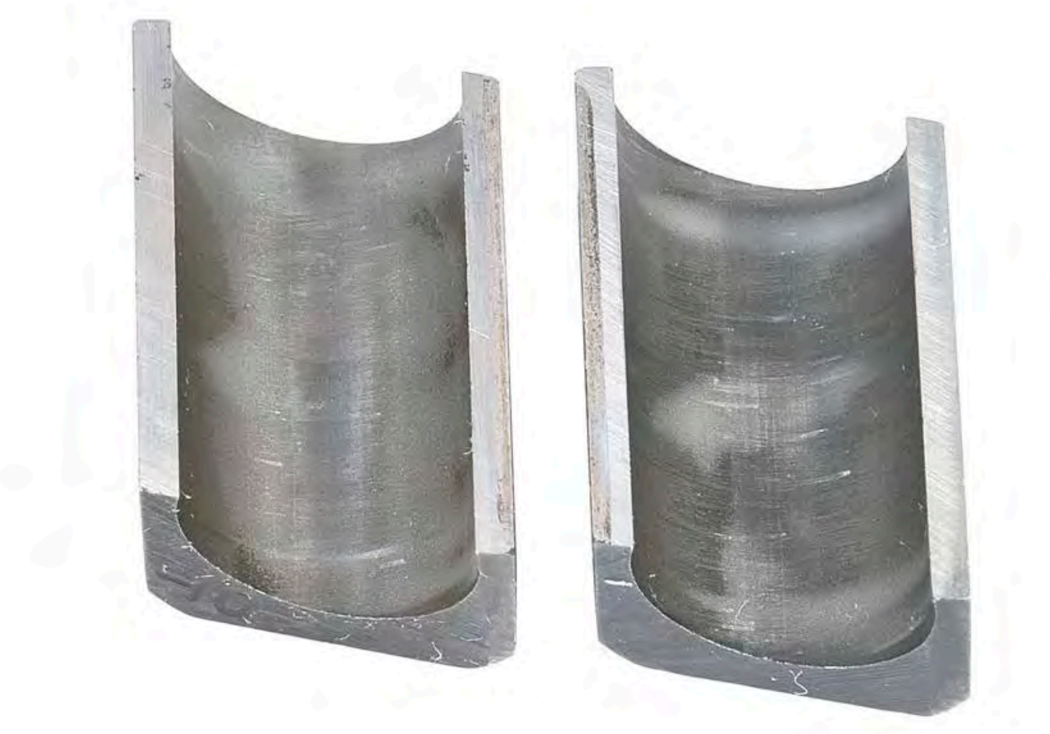
SN15442663 Transfer Pump Blades (Side), After

SN15442663 Transfer Pump Blades (Profile), Before

SN15442663 Transfer Pump Blades (Profile), After



SN15442663 Shoes (Front), Before



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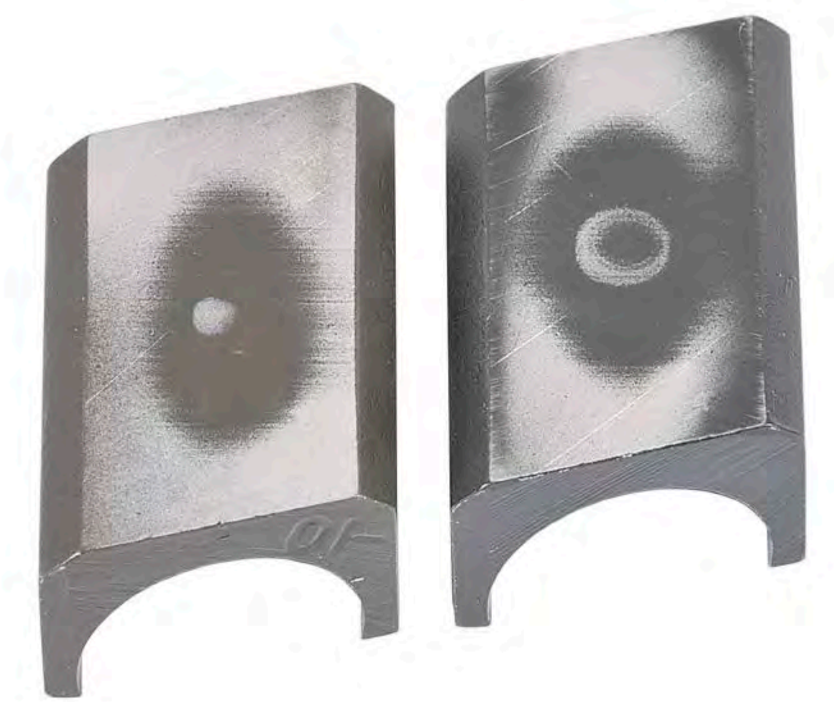

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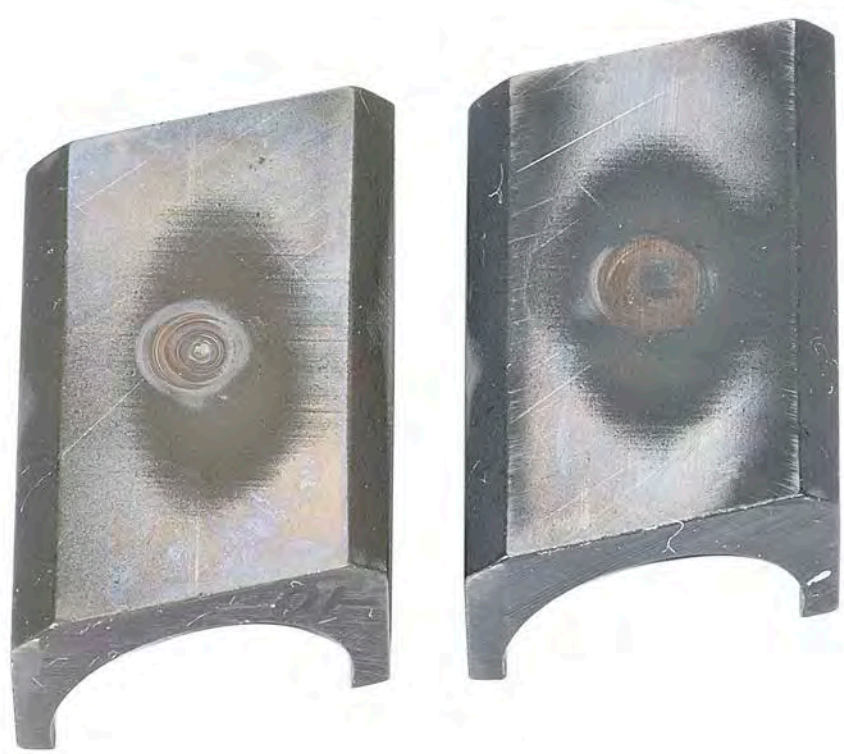


SN15442663 Shoes (Back), After

SN15442663 Rollers, Before

SN15442663 Rollers, After

SN15442663 Piston Plungers, Before

SN15442663 Piston Plungers, After

SN15442663 Thrust Washer, Before

SN15442663 Thrust Washer, After

SN15442663 Governor Weight, Before

SN15442663 Governor Weight, After

SN15442663 Cam Ring, Before

SN15442663 Cam Ring, After

SN15442663 Eccentric Ring, Before

SN15442663 Eccentric Ring, After

SN15442663 Rotor (Front), Before

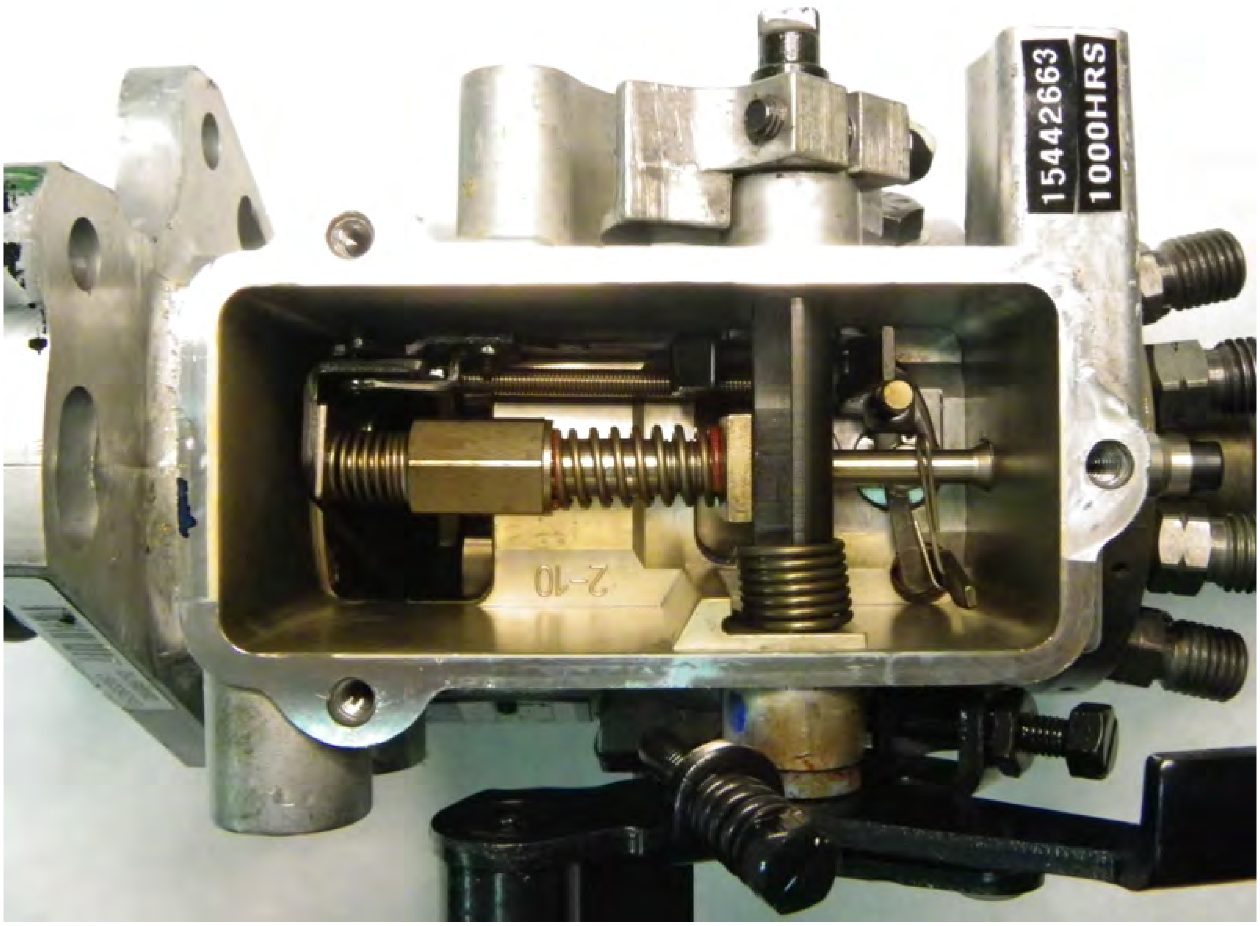
SN15442663 Rotor (Front), After

SN15442663 Rotor (Back), Before

SN15442663 Rotor (Back), After

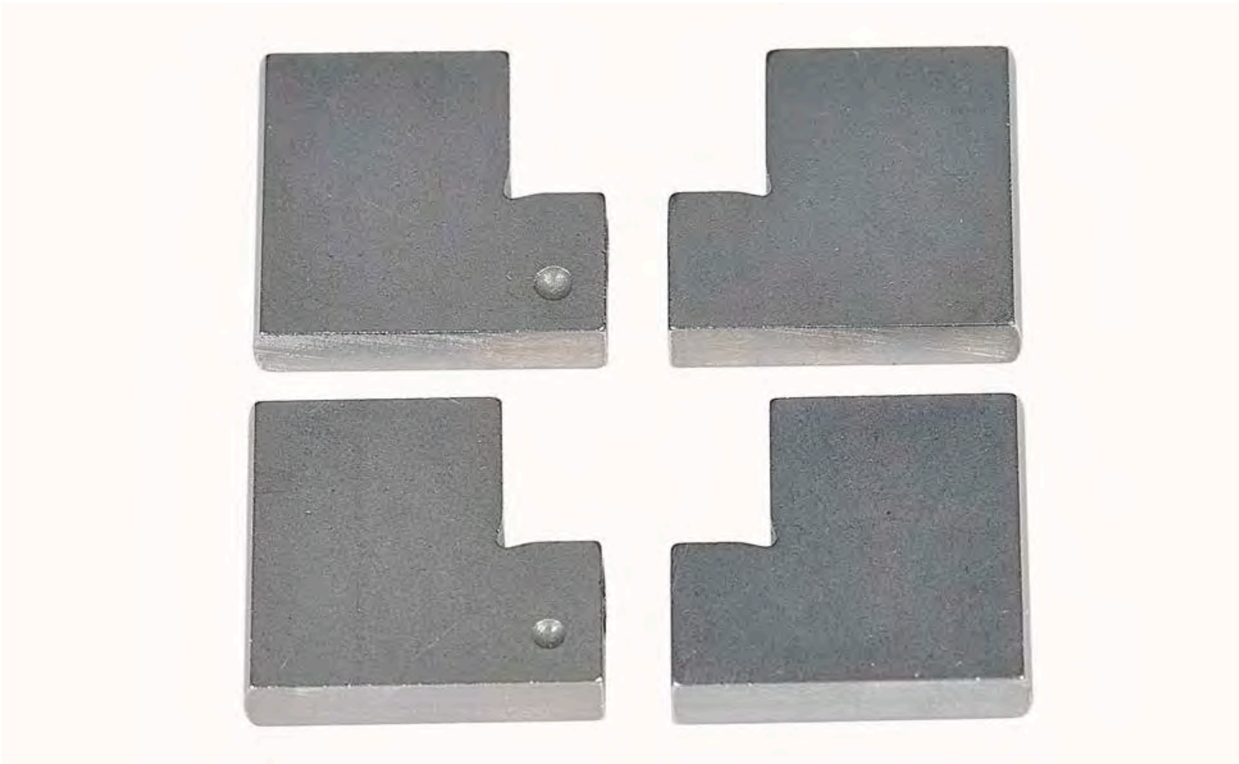
SN15442663 Drive Tang, Before

SN15442663 Drive Tang, After

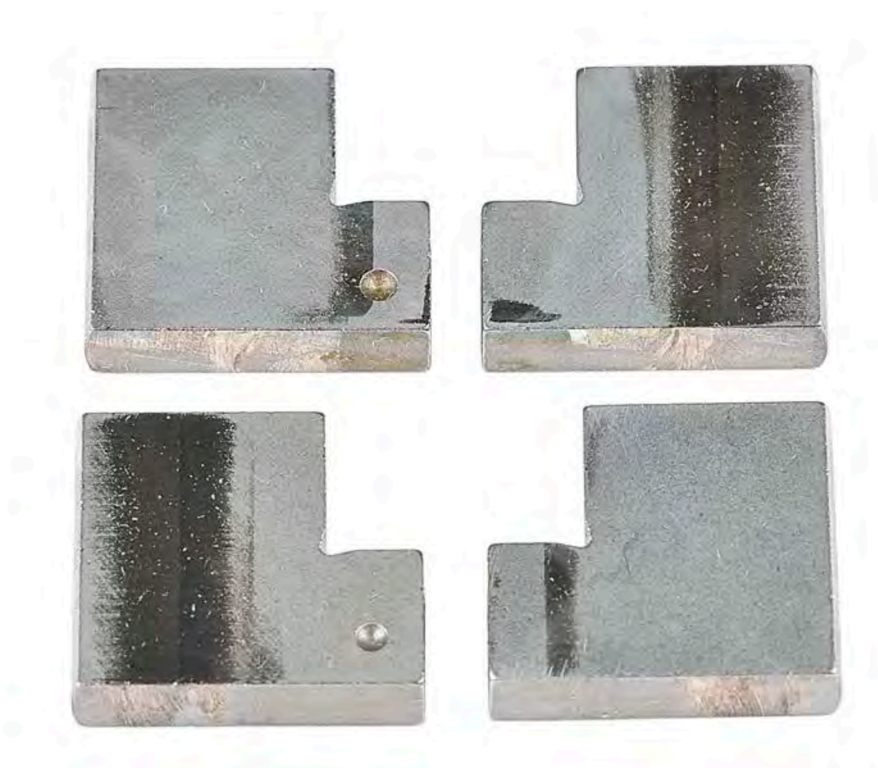


SN15442663 Governor Assembly

PHOTOGRAPHS FOR RIGHT PUMP



SN15442664 Transfer Pump Blades, Before



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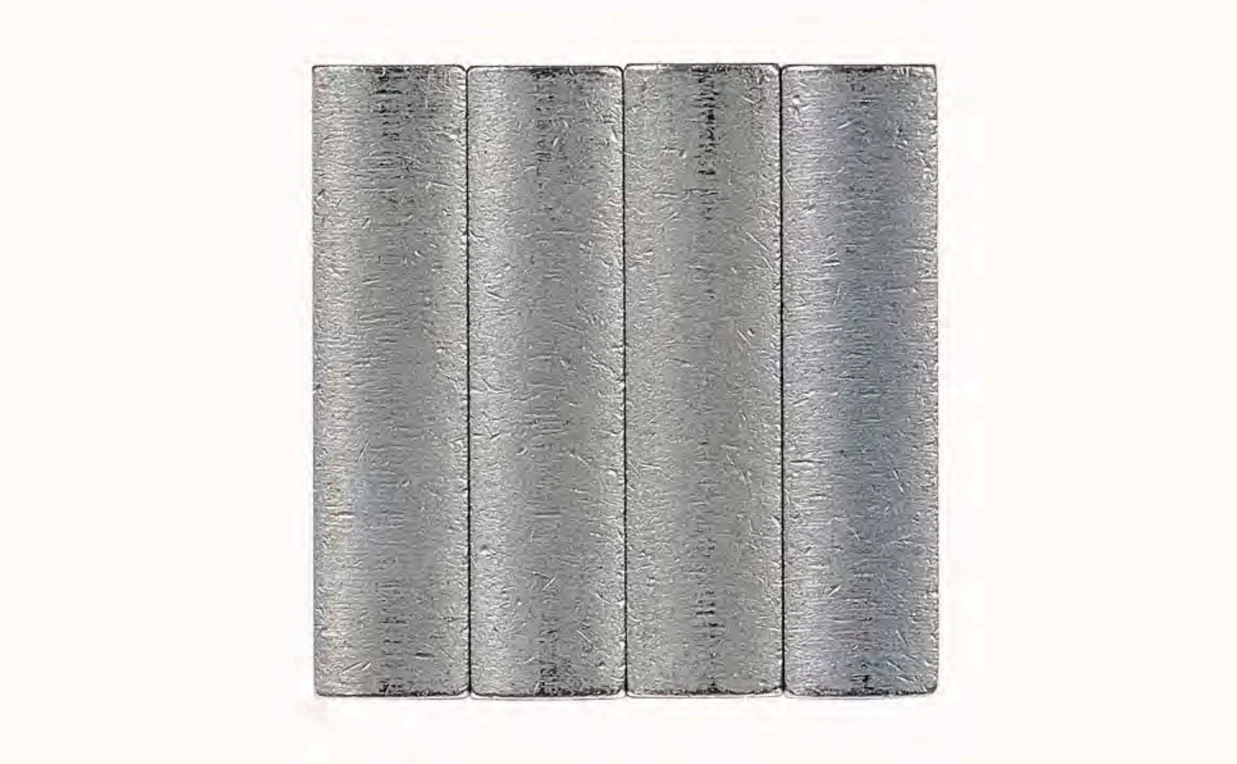
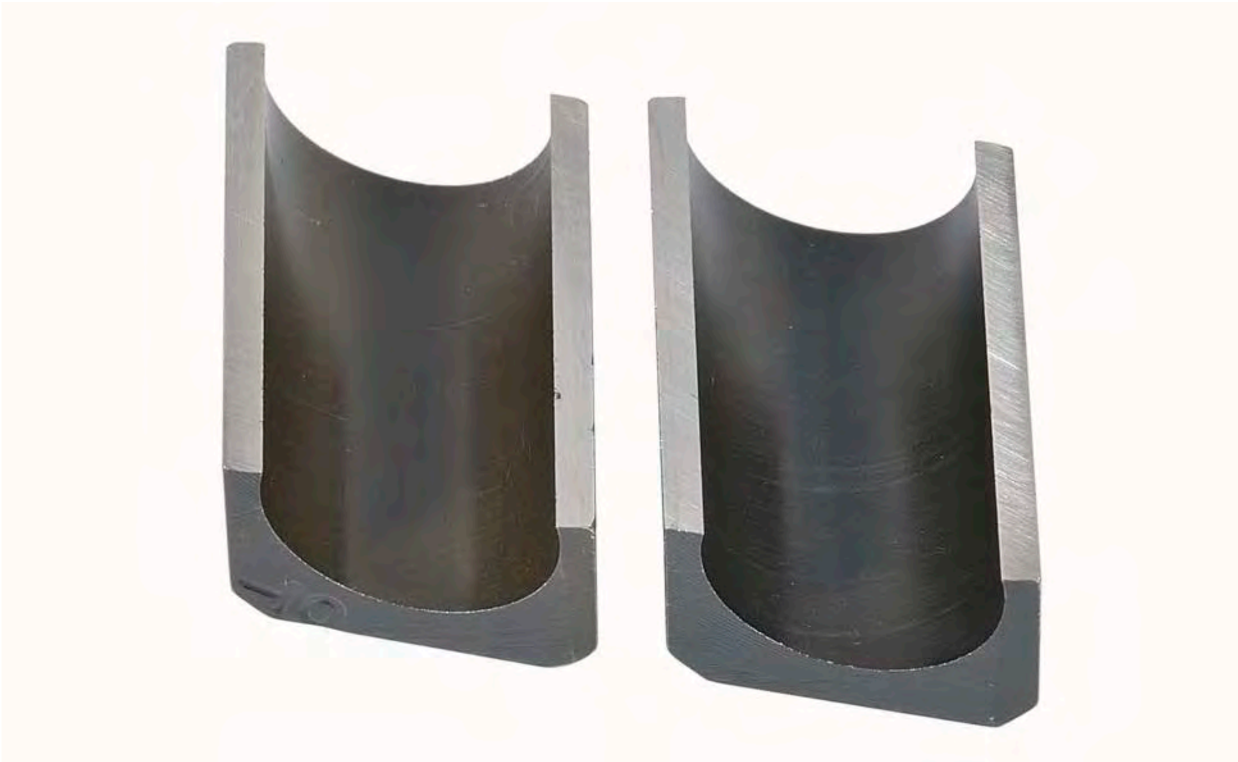
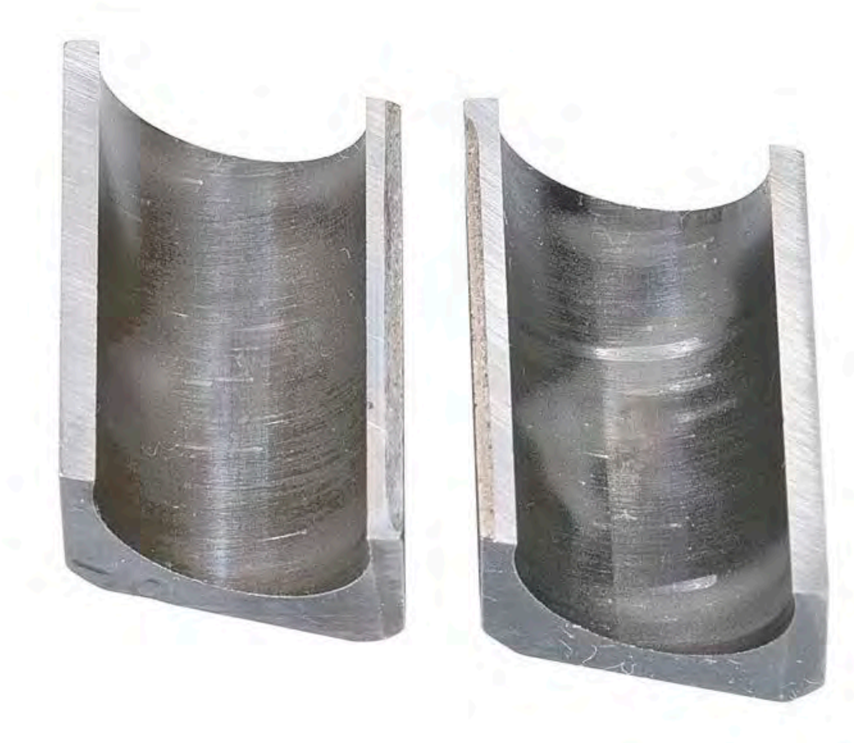


SN15442664 Transfer Pump Blades (Profile), Before

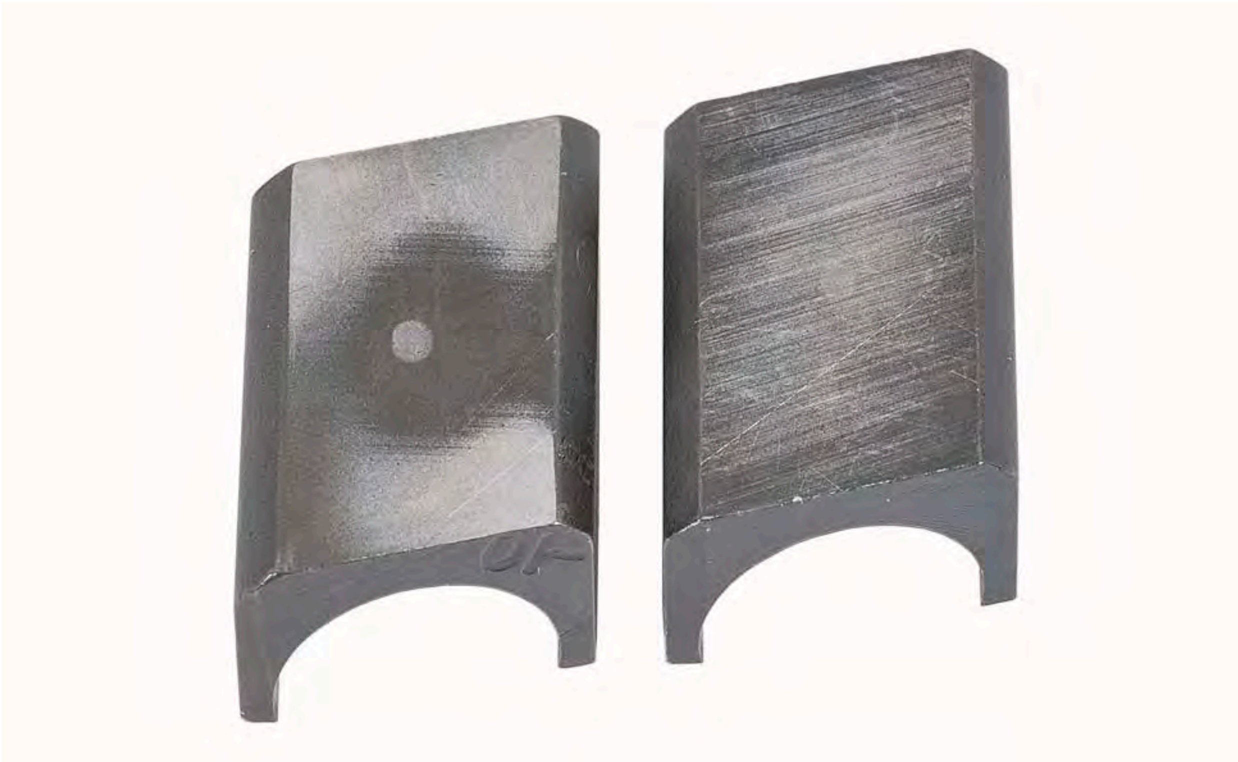
SN15442664 Transfer Pump Blades (Profile), After



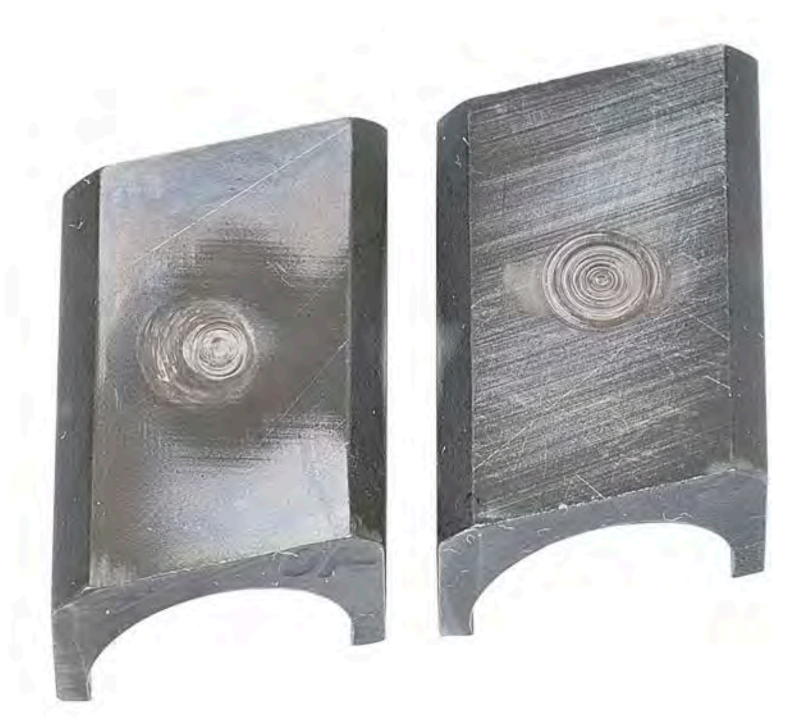
SN15442664 Shoes (Front), Before



SN15442664 Shoes (Front), After



SN15442664 Shoes (Back), Before



SN15442664 Shoes (Back), After

SN15442664 Rollers, Before

SN15442664 Rollers, After

SN15442664 Piston Plungers, Before

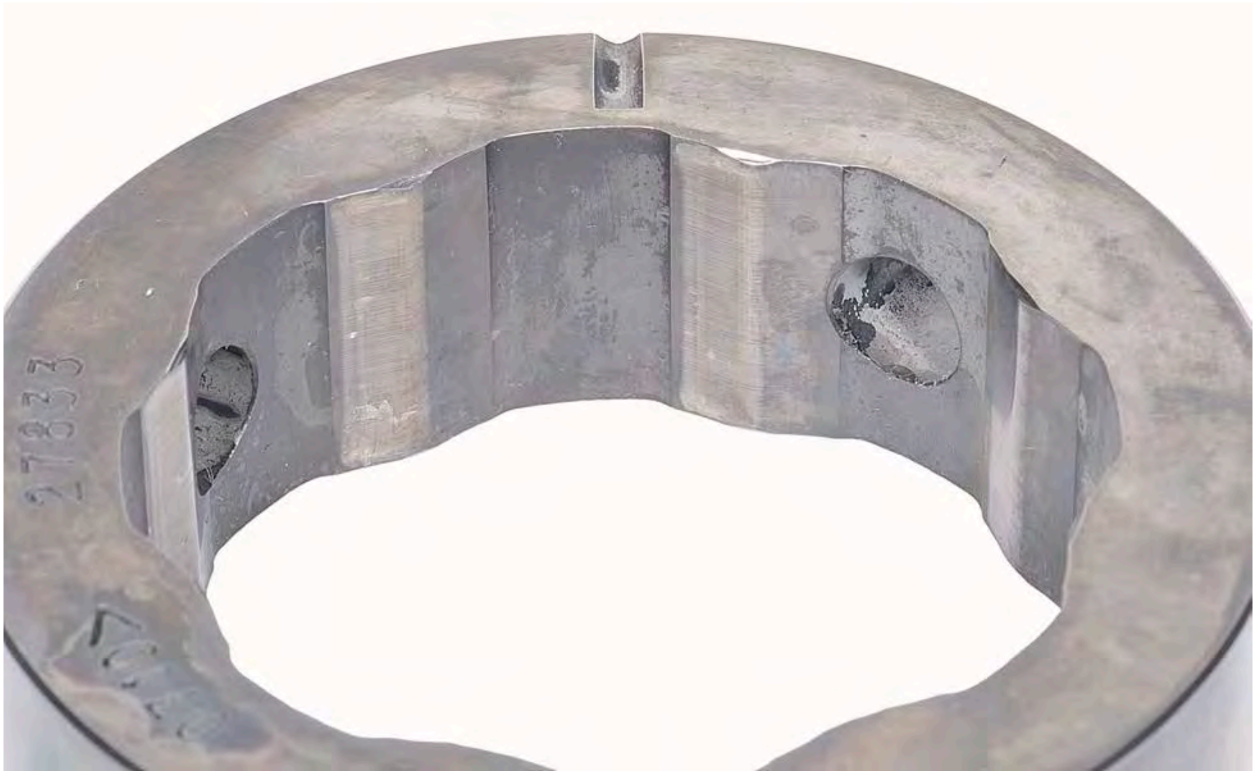
SN15442664 Piston Plungers, After

SN15442664 Thrust Washer, Before

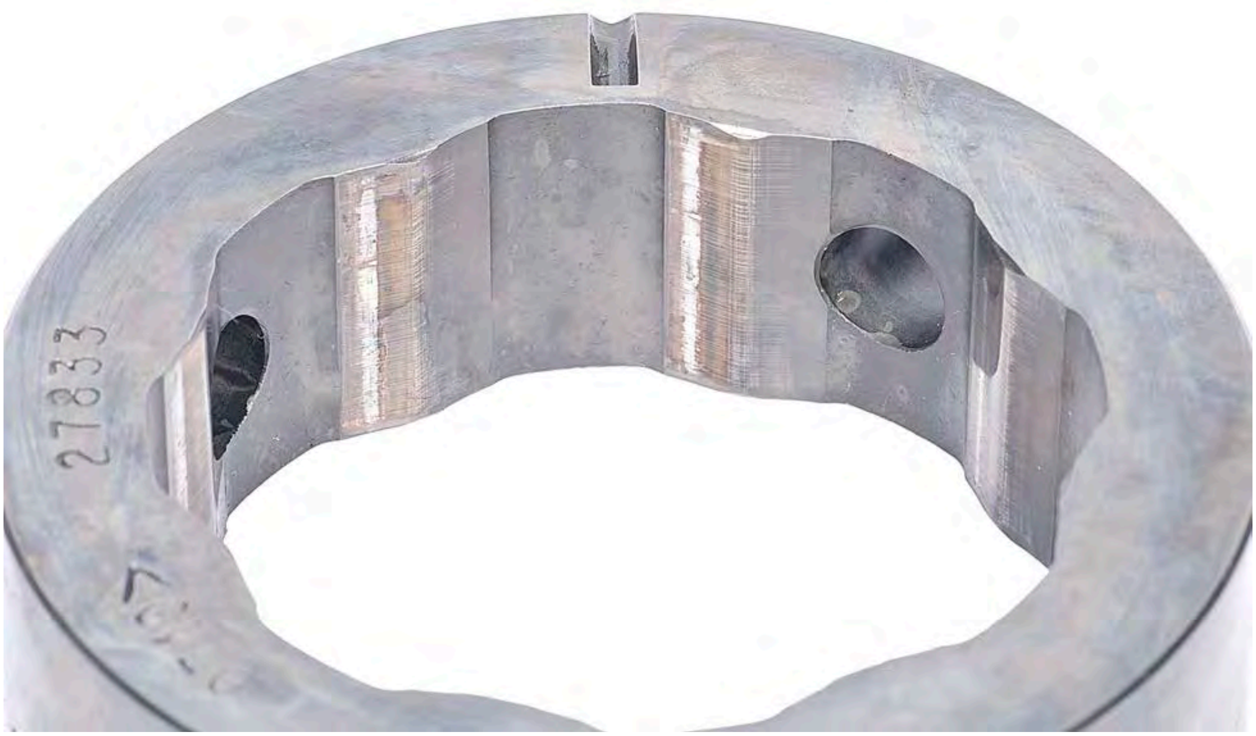
SN15442664 Thrust Washer, After

SN15442664 Governor Weight, Before

SN15442664 Governor Weight, After



SN15442664 Cam Ring, Before



SN15442664 Cam Ring, After

SN15442664 Eccentric Ring, Before

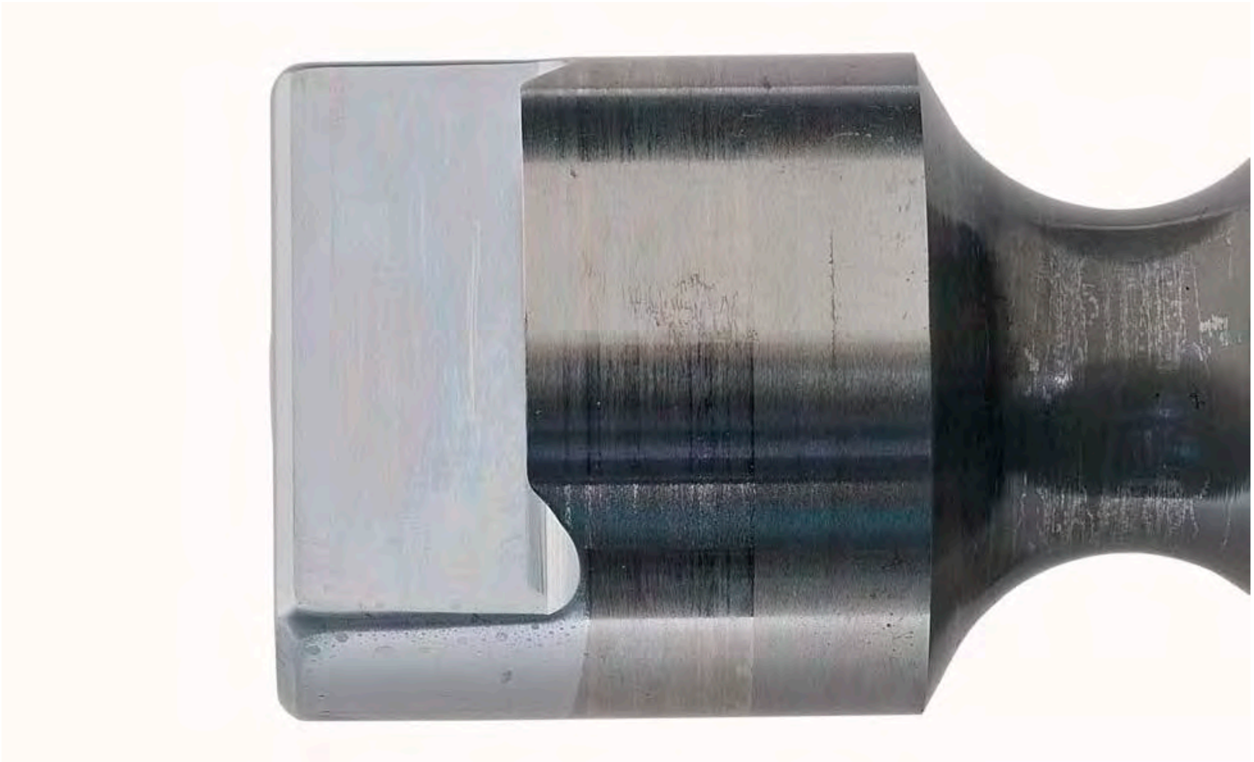
SN15442664 Eccentric Ring, After

SN15442664 Rotor (Front), Before

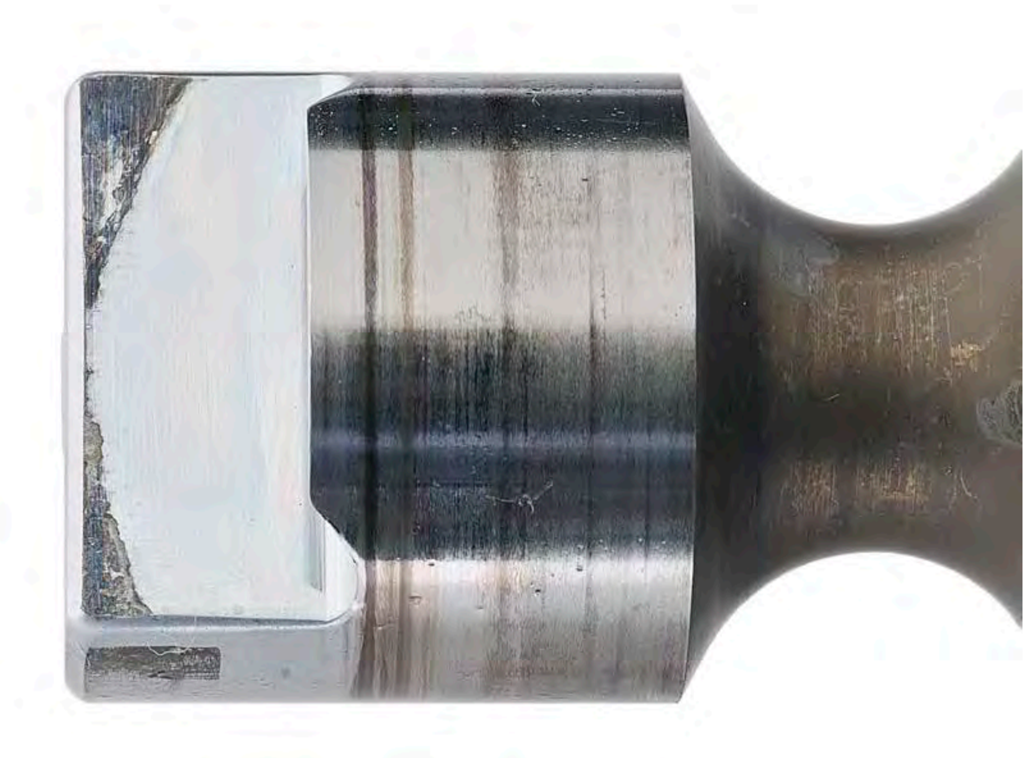
SN15442664 Rotor (Front), After

SN15442664 Rotor (Back), Before

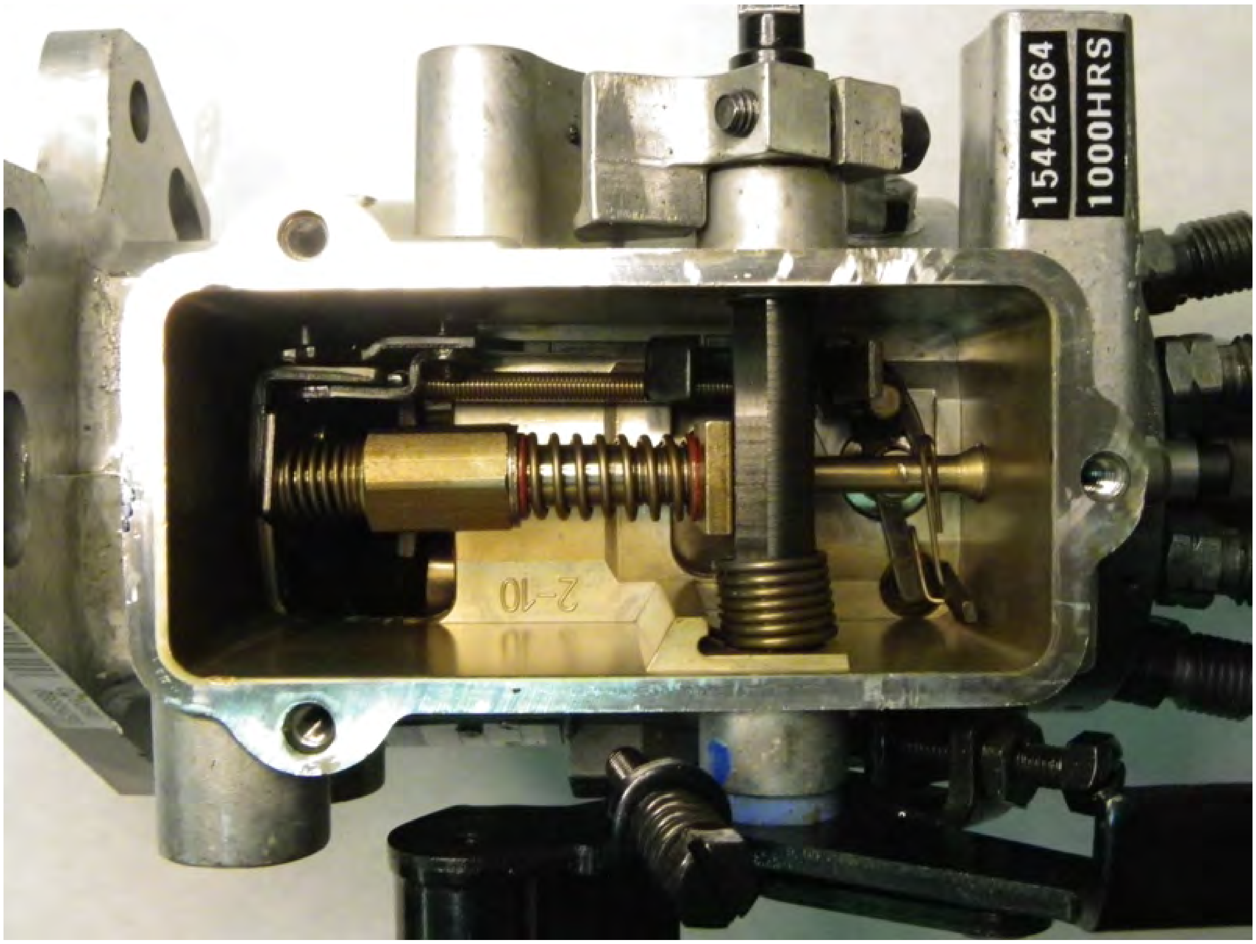
SN15442664 Rotor (Back), After



SN15442664 Drive Tang, Before



SN15442664 Drive Tang, After



SN15442664 Governor Assembly

APPENDIX U

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Test Fuel Description: FT-SPK/Jet A-1 with 9-mg/L DCI-4A
Test Number: FTJA9-C3T21-77-1000

EFFECTIVENESS OF ADDITIVES IN IMPROVING FUEL LUBRICITYAND PREVENTING ROTARY PUMP FAILURE AT HIGH TEMPERATURES

Project 14734.04.330

Stanadyne Rotary Pump DB2831-5079

Test Fuel Description: FT-SPK/Jet A-1 with 9-mg/L DCI-4A

Test Fuel ID: AF7090

Test Temperature: 77°C (170°F)

Test Number: FTJA9-C3T21-77-1000

Start of Test Date: May 17, 2011

End of Test Date: June 15, 2012

Test Duration: 418 Hrs

Conducted for

U.S. Army TARDEC

Force Projection Technologies

Warren, Michigan

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Stanadyne Rotary Pump Description

The Stanadyne arctic pumps used for this program are opposed-piston, inlet-metered, positive-displacement, rotary-distributor, fuel-lubricated injection pumps, model DB2831-5079, for a General Motors application. The arctic pump is equipped with hardened transfer pump blades, transfer pump liner, governor thrust washer, and drive shaft tang to reduce wear in these critical areas of the pump. A schematic diagram of the principal pump components is provided in Figure U-1.

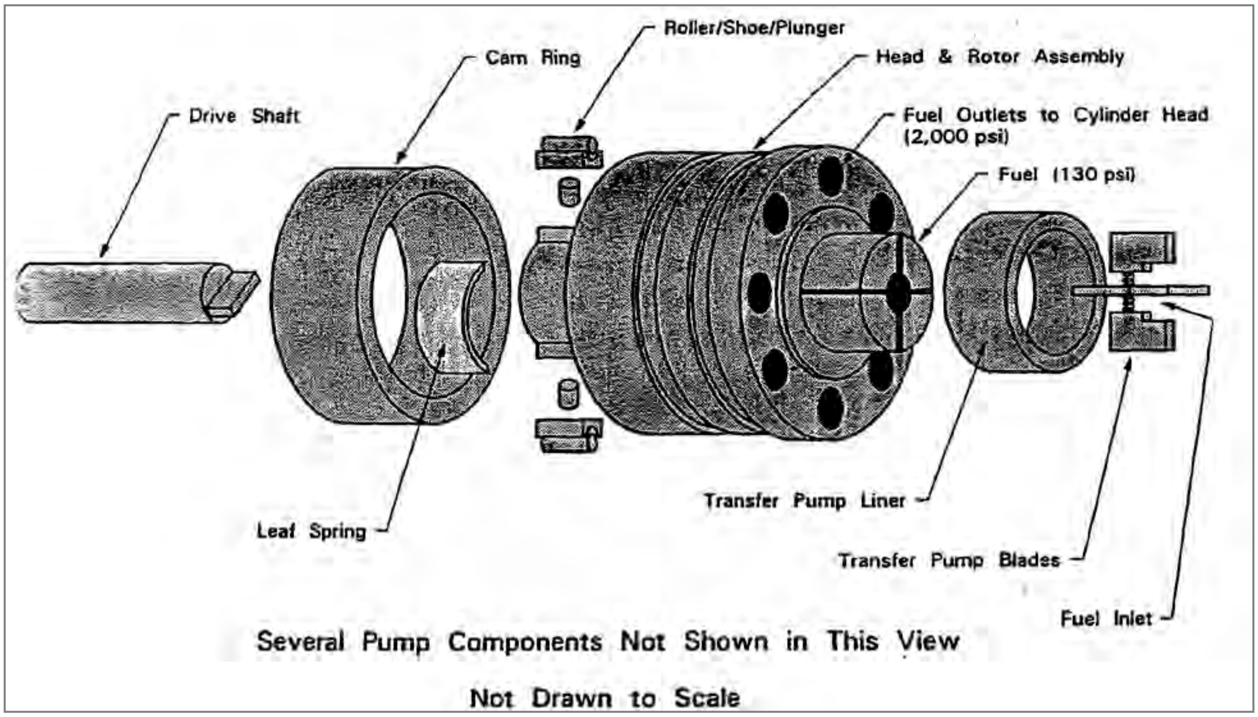


Figure U-1. Schematic Diagram of Principal Pump Components

Cycle Description

Stanadyne fuel injection pump endurance testing consists of the fuel injection pump operation on a controlled test stand for a specified duration. Testing continues until the specified duration is met, or until major performance degradation is experienced, whichever occurs first. All factory pumps, high pressure lines, and fuel injectors are used to ensure similar performance on the test stand as would be seen in vehicle. The test cycle is used to determine varying fuel properties impact on pump and injector performance over an accelerated life span. This is accomplished by operating the pumps at rated speed (fuel flow) conditions as outlined in Stanadyne calibration specifications, while supplying test fuel at controlled inlet pressure and temperature conditions. Overall pump performance degradation can be monitored throughout testing in several ways; large changes (increase/decrease) of injected flow rate, increases in fuel pump return fuel temperature, increases in pump body temperature, and changes in pump housing pressure. All important pump parameters are monitored and recorded throughout testing to monitor pump performance versus test time.

Operating Summary

Test cycle operating parameters can be seen below in Table U-1.

Table U-1. Test Cycle Operating Parameters

Parameter	Test Conditions
Pump Speed, RPM	1700 +/- 10
Fuel Inlet Pressure, psi	3 +/- 1
Fuel Inlet Temperature, °C	77 +/- 5

Statistical information on pump operating conditions over the endurance cycle can be seen below in Table U-2.

Table U-2. Pump Operation Summary

Test Point	Description	Average	Std Dev
PUMP_SPD	Pump Speed [rpm]	1700	1.1213
FLO_R	Injeted Flowrate [mL/min]	673	100.4
FUELIN_P	Fuel Inlet Pressure [psig]	3	0.182
TRNS_P_R	Transfer Pump Pressure [psig]	70.4	10.47
HSG_P_R	Pump Housing Pressure [psig]	13.3	2.51
RTRN_T_R	Fuel Return Temperature [°C]	77	0.72
FUEL_T	Fuel Tank Temperature [°C]	30.6	2.2
FUELIN_T	Fuel Inlet Temperature [°C]	76.7	0.33

Graphical Plots

Graphical plots for key operating conditions for Moving Average Flow Rate, Transfer Pump Housing Pressure, and Fuel Inlet & Return Temperature, Moving Average, can be seen below in Figure U-2 through Figure U-4.

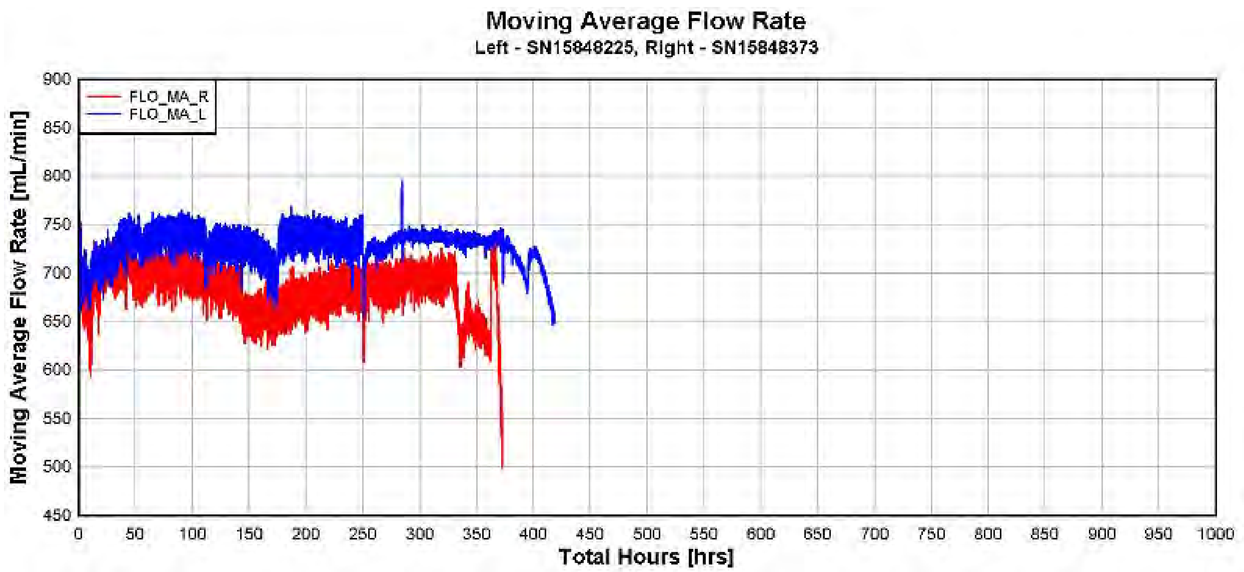


Figure U-2. Pump Flow, Moving Average

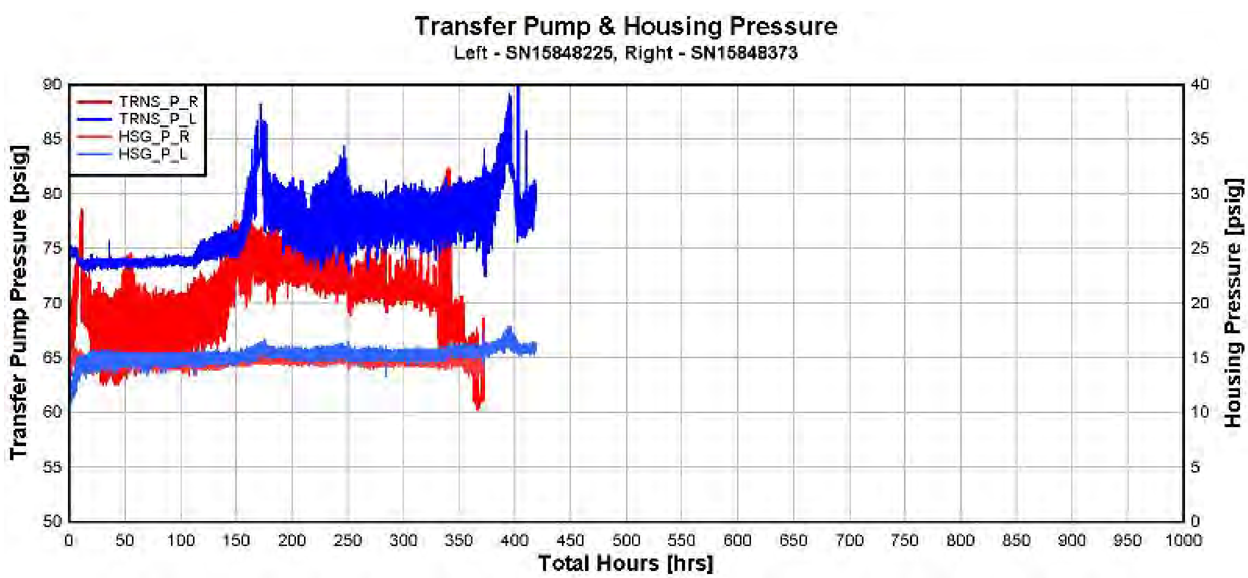


Figure U-3. Transfer Pump & Housing Pressure

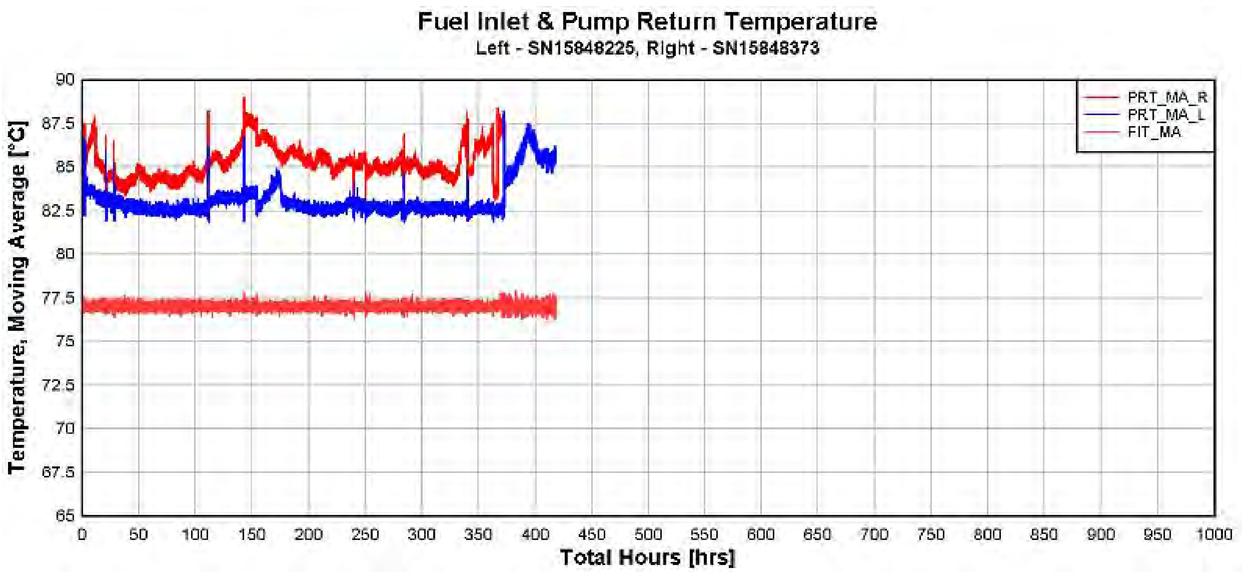


Figure U-4. Fuel Inlet & Return Temperature, Moving Average

Pump Calibration

The new pumps were disassembled, and pre-test roller-to-roller dimensions and transfer pump blade weights were obtained. Roller-to-roller dimensions were set per Stanadyne Diesel Systems Injection Pump Specifications for the DB2831-5079 model. The specification calls for a roller-to-roller dimension setting of 1.975 inches ± .0005 inches. All pumps were set at exactly 1.975 inches with instructions that the roller-to-roller dimension not be adjusted during pre- and post-performance evaluations so that wear in these components could be accurately measured, and comparisons made between fuels. Although there are no min-max specifications other than initial assembly values, wear calculation of the roller-to-roller dimension is an excellent bench mark for the effects of fuel lubricity.

Results for pre and post test pump calibration can be seen below in Table U-3. (Note – Calibration data to be used as reference only).

Table U-3. Stanadyne Pump Calibration, Pre and Post Test

Pump Type : DB2831-5079 (arctic)				Test Number: 21			Test Duration : 1000-hrs.		
Test Fuel : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 170°F				SN : 15848225			SN : 15848373		
PUMP RPM	*Description*	*Specification*		*Pump Duration : 418.-hrs.*			*Pump Duration : 372.-hrs.*		
		Min	*Max*	*Before*	*After*	*Change*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60 psi	62 psi	62 psi	61 psi	1 psi	62 psi	61 psi	1 psi
	Return Fuel	225 cc	375 cc	304 cc	350 cc	-46 cc	282 cc	298 cc	-16 cc
350	Low Idle	12 cc	16 cc	16 cc	**4 cc**	13 cc	15 cc	**46 cc**	-31 cc
	Housing psi.	8 psi	12 psi	10.5 psi	10.0 psi	.5 psi	10.0 psi	**4.0 psi**	6.0 psi
	Advance	3.50°		**3.06°**	**1.10°**	1.96°	6.41°	4.85°	1.56°
	Cold Advance Solenoid	.0 psi	1.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi	.0 psi
750	Shut-Off		4.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc	.0 cc
900	Fuel Delivery	66.5 cc	69.5 cc	68.0 cc	**71.0 cc**	-3.0 cc	69.0 cc	**53.0 cc**	16.0 cc
1600	WOT Fuel delivery	60 cc		65 cc	65 cc	cc	68 cc	**49 cc**	19 cc
	WOT Advance	2.50°	3.50°	3.10°	3.03°	.07°	2.98°	**4.22°**	-1.24°
	Face Cam Fuel delivery	21.5 cc	23.5 cc	22.0 cc	23.0 cc	-1.0 cc	22.0 cc	**21.0 cc**	1.0 cc
	Face Cam Advance	5.25°	7.25°	6.17°	**3.64°**	2.53°	6.63°	**8.57°**	-1.94°
	Low Idle	11.0°	12.0°	**9.9°**	**8.1°**	1.8°	**10.7°**	**10.7°**	-.1°
1825	Fuel Delivery	33 cc		38 cc	45 cc	-7 cc	37 cc	48 cc	-11 cc
1950	High Idle		15 cc	cc	2 cc	-2 cc	2 cc	**46 cc**	-44 cc
	Transfer pump psi.		125 psi	100 psi	98 psi	2 psi	97 psi	86 psi	11 psi
200	WOT Fuel Delivery	58 cc		63 cc	68 cc	-5 cc	63 cc	**46 cc**	17 cc
	WOT Shut-Off		4 cc	0 cc	0 cc	0 cc	0 cc	0 cc	0 cc
75	Low Idle Fuel Delivery	37 cc		56 cc	59 cc	-3 cc	56 cc	**34 cc**	22 cc
	Transfer pump psi.	16 psi		24 psi	21 psi	3 psi	21 psi	**15 psi**	6 psi
	Housing psi.	.0 psi	12 psi	9.5 psi	8 psi	2 psi	9 psi	1 psi	8 psi
	Air Timing	-1.00°	.00°	.00°	-.50°	.50°	-.50°	**.50°**	-1.00°

Bold numbers = out of specification results

Notes :

Metrology

Before and after testing injection pumps are torn down and measured to document internal wear accumulated over the endurance cycle. The primary measurements taken are the transfer pump blade weights, and documentation of the roller to roller dimensions. This data can be seen below in Table U-4 and Table U-5.

Table U-4. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15848225	Test Number: 21	
Fuel Description : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 170°F				
	Date:	10/12/2011	7/29/2012	
Transfer Pump Blade 1		***0-hrs.***	***418.-hrs.***	***Change***
Measurement 1	Mass (g)	3.2063	3.2042	-0.0021
Measurement 2		3.2062	3.2041	-0.0021
Measurement 3		3.2061	3.2041	-0.0020
Measurement 4		3.2061	3.2042	-0.0019
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.1846	3.1820	-0.0026
Measurement 2		3.1846	3.1820	-0.0026
Measurement 3		3.1844	3.1821	-0.0023
Measurement 4		3.1844	3.1822	-0.0022
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.1893	3.1877	-0.0016
Measurement 2		3.1891	3.1875	-0.0016
Measurement 3		3.1892	3.1876	-0.0016
Measurement 4		3.1891	3.1876	-0.0015
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2170	3.2137	-0.0033
Measurement 2		3.2171	3.2137	-0.0034
Measurement 3		3.2171	3.2138	-0.0033
Measurement 4		3.2172	3.2139	-0.0033
Average Measurements		***0-hrs.***	***418.-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2062	3.2042	-0.0020
Transfer Pump Blade 2		3.1845	3.1821	-0.0024
Transfer Pump Blade 3		3.1892	3.1876	-0.0016
Transfer Pump Blade 4		3.2171	3.2138	-0.0033
	Roller to Roller (in)	1.9760	1.9789	0.0029
	Eccentricity (in.)	0.0010	0.0020	0.0010
	Drive Backlash (In)	0.0045	0.0040	-0.0005

Table U-5. Blade & Roller-To-Roller Measurements

Pump Type : DB2831-5079 (arctic)		SN: 15848373	Test Number: 21	
Fuel Description : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 170°F				
	Date:	10/12/2011	7/29/2012	
Transfer Pump Blade 1		***0-hrs.***	***372-hrs.***	***Change***
Measurement 1	Mass (g)	3.2218	3.2217	-0.0001
Measurement 2		3.2218	3.2218	0.0000
Measurement 3		3.2218	3.2218	0.0000
Measurement 4		3.2219	3.2219	0.0000
Transfer Pump Blade 2				***Change***
Measurement 1	Mass (g)	3.2161	3.2155	-0.0006
Measurement 2		3.2163	3.2155	-0.0008
Measurement 3		3.2162	3.2153	-0.0009
Measurement 4		3.2161	3.2153	-0.0008
Transfer Pump Blade 3				***Change***
Measurement 1	Mass (g)	3.2424	3.2378	-0.0046
Measurement 2		3.2424	3.2379	-0.0045
Measurement 3		3.2425	3.2381	-0.0044
Measurement 4		3.2424	3.2380	-0.0044
Transfer Pump Blade 4				***Change***
Measurement 1	Mass (g)	3.2030	3.2038	0.0008
Measurement 2		3.2030	3.2037	0.0007
Measurement 3		3.2030	3.2037	0.0007
Measurement 4		3.2029	3.2036	0.0007
Average Measurements		***0-hrs.***	***372-hrs.***	***Change***
Transfer Pump Blade 1	Mass (g)	3.2218	3.2218	0.0000
Transfer Pump Blade 2		3.2162	3.2154	-0.0008
Transfer Pump Blade 3		3.2424	3.2380	-0.0045
Transfer Pump Blade 4		3.2030	3.2037	0.0007
	Roller to Roller (in)	1.9760	1.9663	-0.0097
	Eccentricity (in.)	0.0040	0.0160	0.0120
	Drive Backlash (In)	0.0050	0.0680	0.0630

Fuel Injector Results

Fuel injector nozzle tests were performed in accordance with procedures set forth in an approved 6.5L diesel engine manual using diesel nozzle tester J 29075 – B. Nozzle testing is comprised of the following checks:

- Nozzle Opening Pressure
- Leakage
- Chatter
- Spray Pattern

Each test is considered independent of the others, and if any one of the tests is not satisfied, the injector should be replaced.

The normal opening pressure specification for these injectors is 1500 psig minimum. The specified nozzle leakage test involves pressurizing the injector nozzle to 1400 psig and holding for 10 seconds – no fuel droplets should separate from the injector tip. The chatter and spray pattern evaluations are subjective. A sharp audible chatter from the injector and a finely misted spray cone are required. Results for the injectors used in Test 1 are shown in Table U-6.

Table U-6. Injector Nozzle Test

Stanadyne Rotary Pump Lubricity Evaluation 6.5L Fuel Injector Test Inspection												
Test No.	Inj. Pump ID No.	Fuel	Inj. ID No.	Opening Pressure 1500-psig Min.		Tip Leakage no drop off in 10 sec. @ 1400 psig		Chatter Test Audible Chatter		Spray Pattern Fine Mist	
				Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test	Pre Test	Post Test
21	15848225	FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 170°F	21-1	2050	1925	Pass	Pass	Pass	Pass	Pass	Pass
			21-2	2150	1925	Pass	Pass	Pass	Pass	Pass	Pass
			21-3	2150	1875	Pass	Pass	Pass	Pass	Pass	Pass
			21-4	2175	1975	Pass	Pass	Pass	Pass	Pass	Pass
			21-5	2150	1950	Pass	Pass	Pass	Pass	Pass	Pass
			21-6	2100	1950	Pass	Pass	Pass	Pass	Pass	Pass
			21-7	2100	1875	Pass	Pass	Pass	Pass	Pass	Pass
			21-8	2150	1900	Pass	Pass	Pass	Pass	Pass	Pass
21	15848373	FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 170°F	21-11	2075	1925	Pass	Pass	Pass	Pass	Pass	Pass
			21-12	2175	1850	Pass	Pass	Pass	Pass	Pass	Pass
			21-13	2200	1875	Pass	Pass	Pass	Pass	Pass	Pass
			21-14	2100	1925	Pass	Pass	Pass	Pass	Pass	Pass
			21-15	2200	1900	Pass	Pass	Pass	Pass	Pass	Pass
			21-16	2200	2000	Pass	Pass	Pass	Pass	Pass	Pass
			21-17	2125	1925	Pass	Pass	Pass	Pass	Pass	Pass
			21-18	2075	1925	Pass	Pass	Pass	Pass	Pass	Pass
			Passed 16 out of 16								

Comments :

Ratings

After completion of testing, disassembled pump components receive a visual rating to quantify the severity of component wear accumulated during testing. Ratings are evaluated on a scale of 0 to 5, with 0 representing a component in new condition, and 5 representing a failed component. Post test component rating information can be seen below in Table U-7 and Table U-8.

Table U-7. Stanadyne Left Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15848225
Test Condition : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 170°F		Pump Duration : 418.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	3
BLADE SPRINGS	Rubbing wear	1
LINER	60% Polishing wear	2
TRANSFER PUMP REGULATOR	Polishing wear	2
REGULATOR PISTON	Polishing wear	2
ROTOR	Wear at distributor ports and wear from drive tang	3.5
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Heavy polishing wear	3.5
PLUNGERS	Heavy polishing wear on left plunger	2.5
SHOES	Dimple, light waer from leaf spring contact	2.5
ROLLERS	Light radial scratches	2
LEAF SPRING	Wear from shoe contact	3
CAM RING	0	2
THRUST WASHER	Polishing wear	1.5
THRUST SLEEVE	Polishing wear from weight contact	1
GOVORNER WEIGHTS	Normal, brown stains	2
LINK HOOK	Wear from thrust washer contact	1.5
METERING VAVLE	Polishing wear	2
DRIVE SHAFT TANG	Excessive chattering wear	4.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Light scorring wear	2.5
HOUSING	Normal, brown stains	1
	AVERAGE DEMERIT RATINGS	2.130

Table U-8. Stanadyne Right Pump Parts Evaluation

Pump Type : DB2831-5079		SN: 15848373
Test Condition : FT-SPK/Jet A-1 w/9-mg/L DCI-4A @ 170°F		Pump Duration : 372.-hrs.
Part Name	**Condition of Part**	**Rating 0 = New 5 = Failed**
BLADES	Wear at rotor slots and liner contact	2.5
BLADE SPRINGS	Rubbing wear	1
LINER	50% Polishing wear	2
TRANSFER PUMP REGULATOR	Polishing wear	2.5
REGULATOR PISTON	Light polishing wear	1.5
ROTOR	Wear at distributor ports and wear from drive tang	3.5
ROTOR RETAINERS	Wear from rotor contact	2
DELIVERY VALVE	Polishing wear	2.5
PLUNGERS	Heavy polishing wear on left plunger	2.5
SHOES	Scorring from rollers, dimple from plungers	3.5
ROLLERS	Radial scorring	3
LEAF SPRING	Wear from shoe contact	3
CAM RING	Wear on lobes from rollers	3.5
THRUST WASHER	Polishing wear	2
THRUST SLEEVE	Wear from governor arm fingers. Brown stains	3
GOVORNER WEIGHTS	Wear from thrust washer contact. Broken weight retainer cage. Brown stains	3
LINK HOOK	Fingers worn excessively	5
METERING VAVLE	Polishing wear	2
DRIVE SHAFT TANG	Excessive shattering wear	4.5
DRIVE SHAFT SEALS	Normal	1
CAM PIN	Normal, in spec	1
ADVANCE PISTON	Light scorring wear	2.5
HOUSING	Deep groove from broken weight retainer. Heavy brown stains	3.5
	AVERAGE DEMERIT RATINGS	2.630

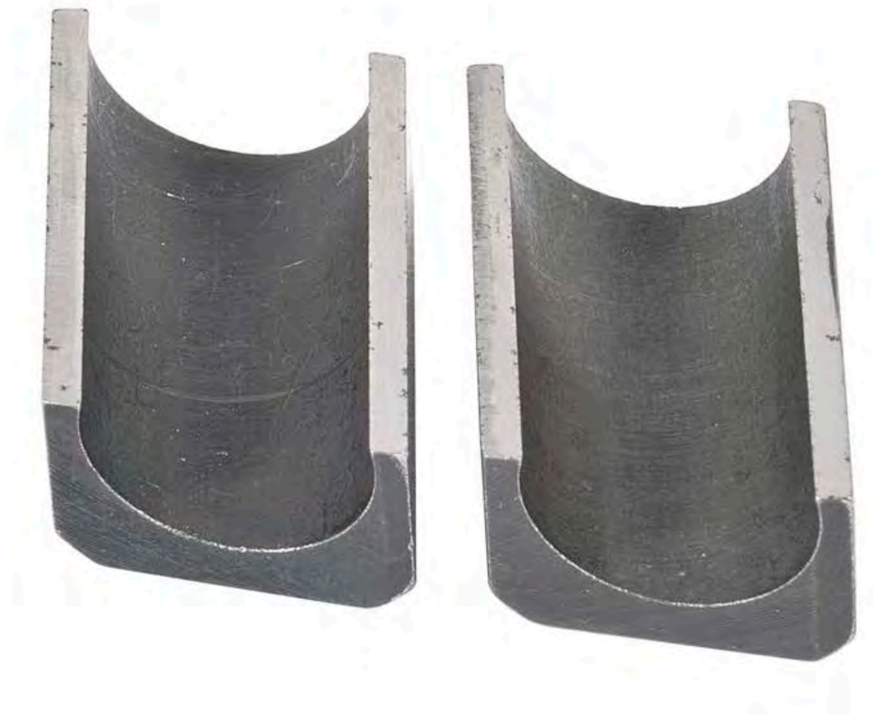
PHOTOGRAPHS FOR LEFT PUMP

SN15848225 Transfer Pump Blades (Side), Before

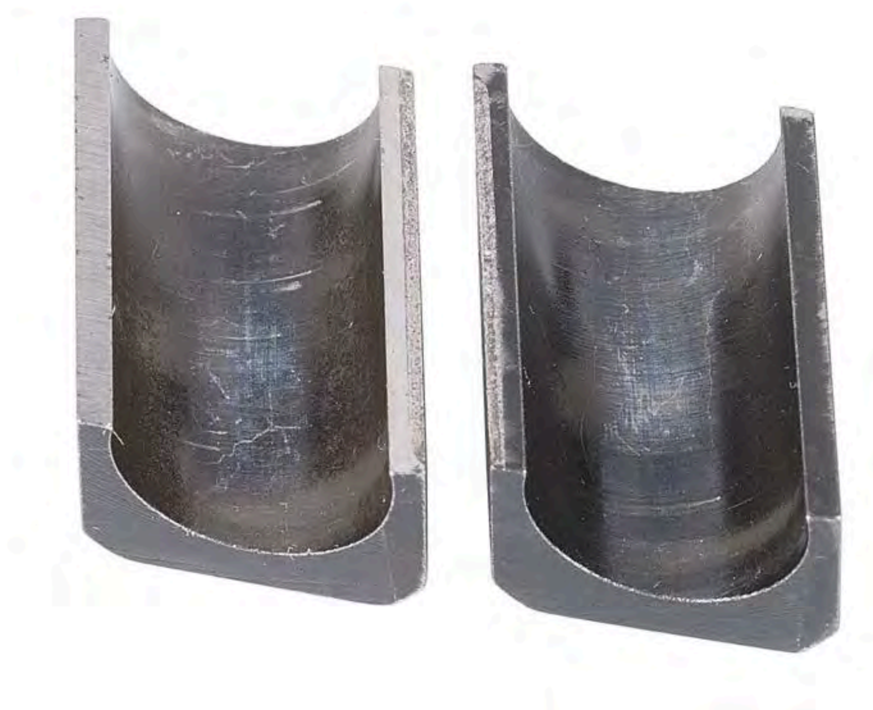
SN15848225 Transfer Pump Blades (Side), After

SN15848225 Transfer Pump Blades (Profile), Before

SN15848225 Transfer Pump Blades (Profile), After



SN15848225 Shoes (Front), Before



SN15848225 Shoes (Front), After

SN15848225 Shoes (Back), Before

SN15848225 Shoes (Back), After

SN15848225 Rollers, Before

SN15848225 Rollers, After

SN15848225 Piston Plungers, Before

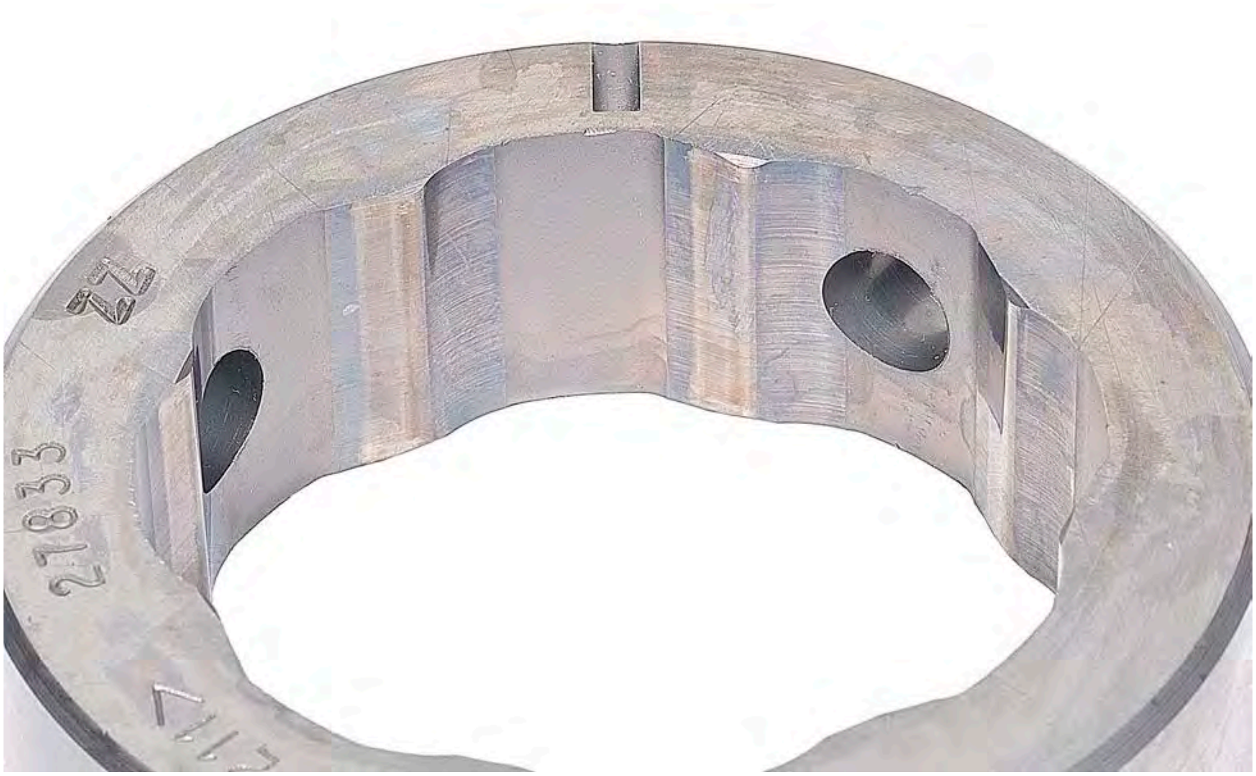
SN15848225 Piston Plungers, After

SN15848225 Thrust Washer, Before

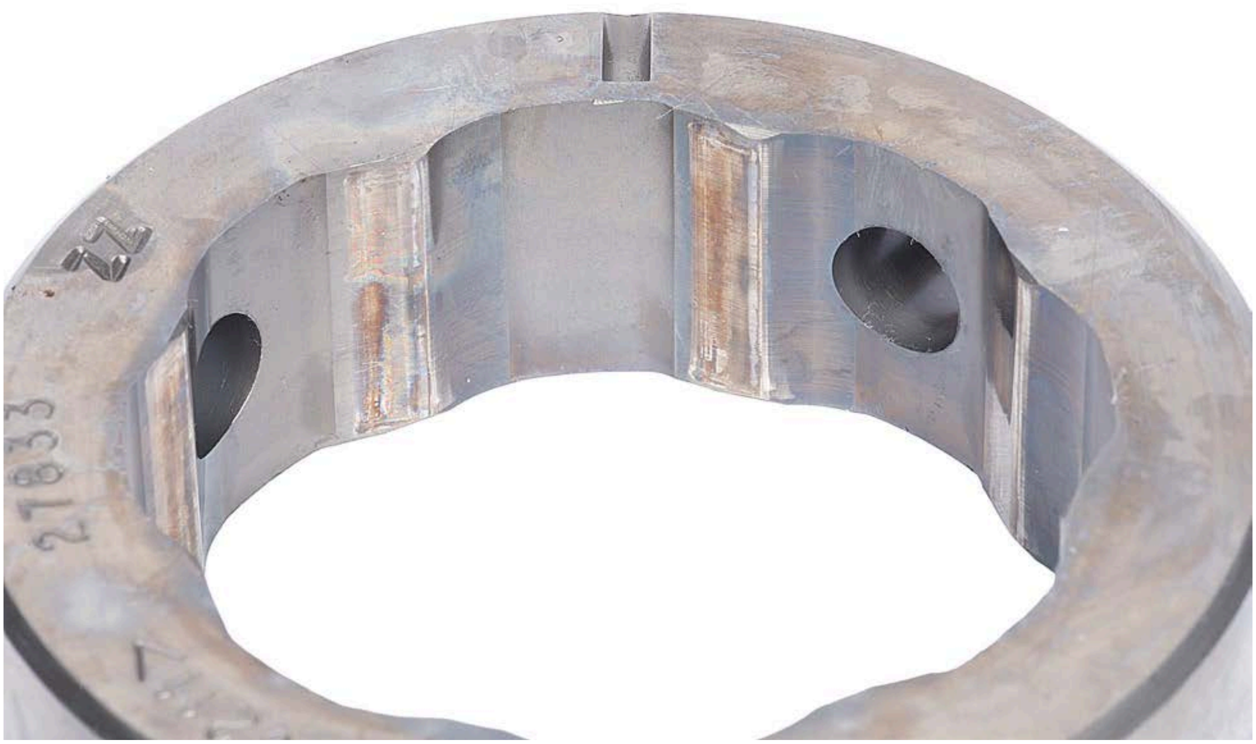
SN15848225 Thrust Washer, After

SN15848225 Governor Weight, Before

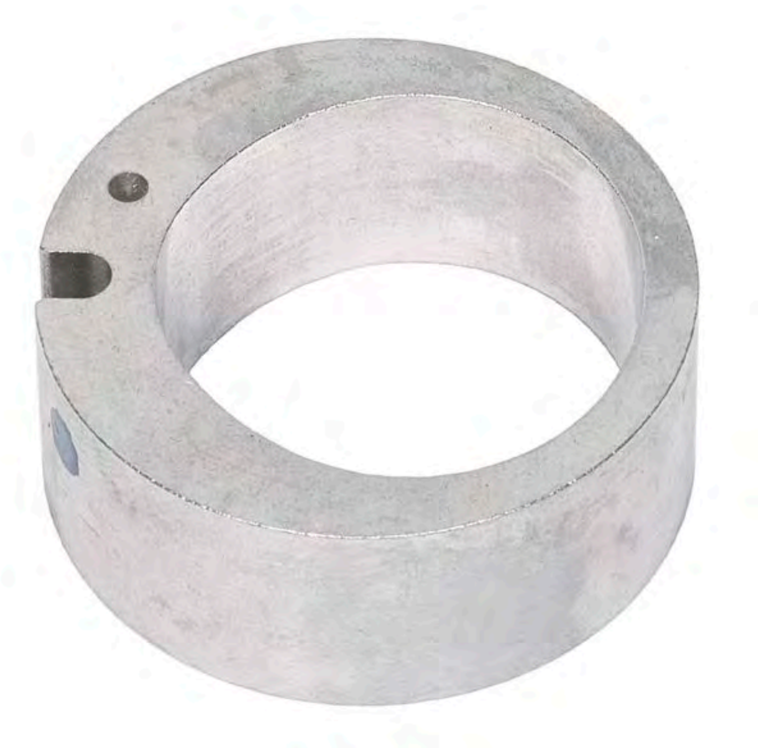
SN15848225 Governor Weight, After



SN15848225 Cam Ring, Before



SN15848225 Cam Ring, After



SN15848225 Eccentric Ring, Before

SN15848225 Eccentric Ring, After

SN15848225 Rotor (Front), Before

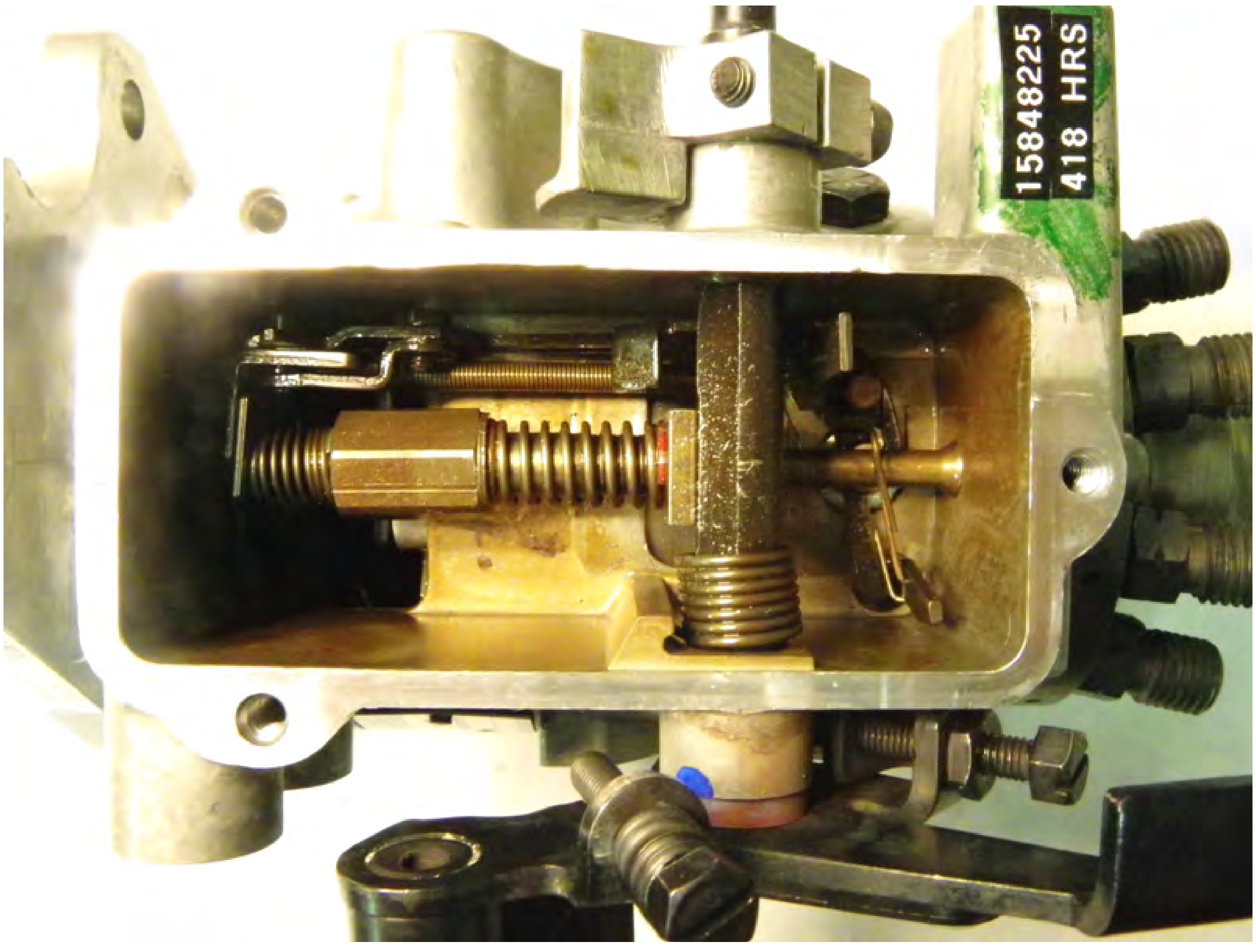
SN15848225 Rotor (Front), After

SN15848225 Rotor (Back), Before

SN15848225 Rotor (Back), After

SN15848225 Drive Tang, Before

SN15848225 Drive Tang, After

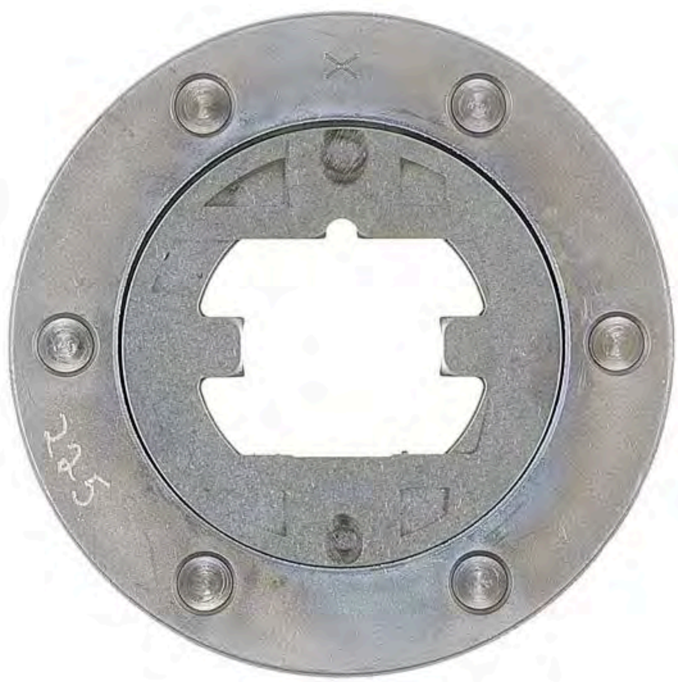


SN15848225 Governor Assembly

SN15848225 Rotor Drive Slot

SN15848225 Rotor Drive Slot Spring

SN15848225 Weight Cage



SN15848225 Weight Cage Back

PHOTOGRAPHS FOR RIGHT PUMP

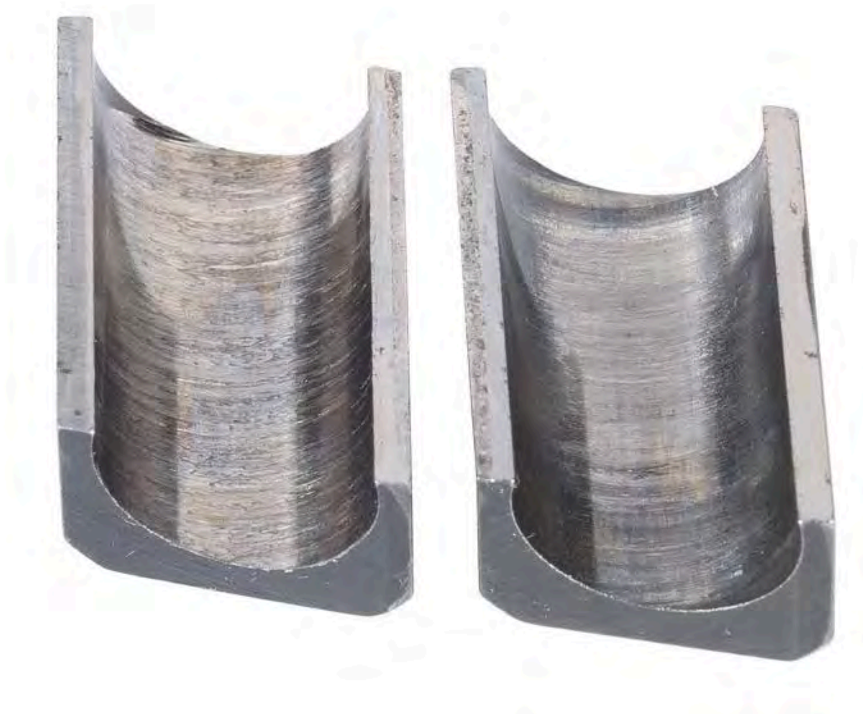
SN15848373 Transfer Pump Blades, Before

SN15848373 Transfer Pump Blades, After

SN15848373 Transfer Pump Blades (Profile), Before

SN15848373 Transfer Pump Blades (Profile), After

SN15848373 Shoes (Front), Before



SN15848373 Shoes (Front), After

SN15848373 Shoes (Back), Before

SN15848373 Shoes (Back), After

SN15848373 Rollers, Before

SN15848373 Rollers, After

SN15848373 Piston Plungers, Before

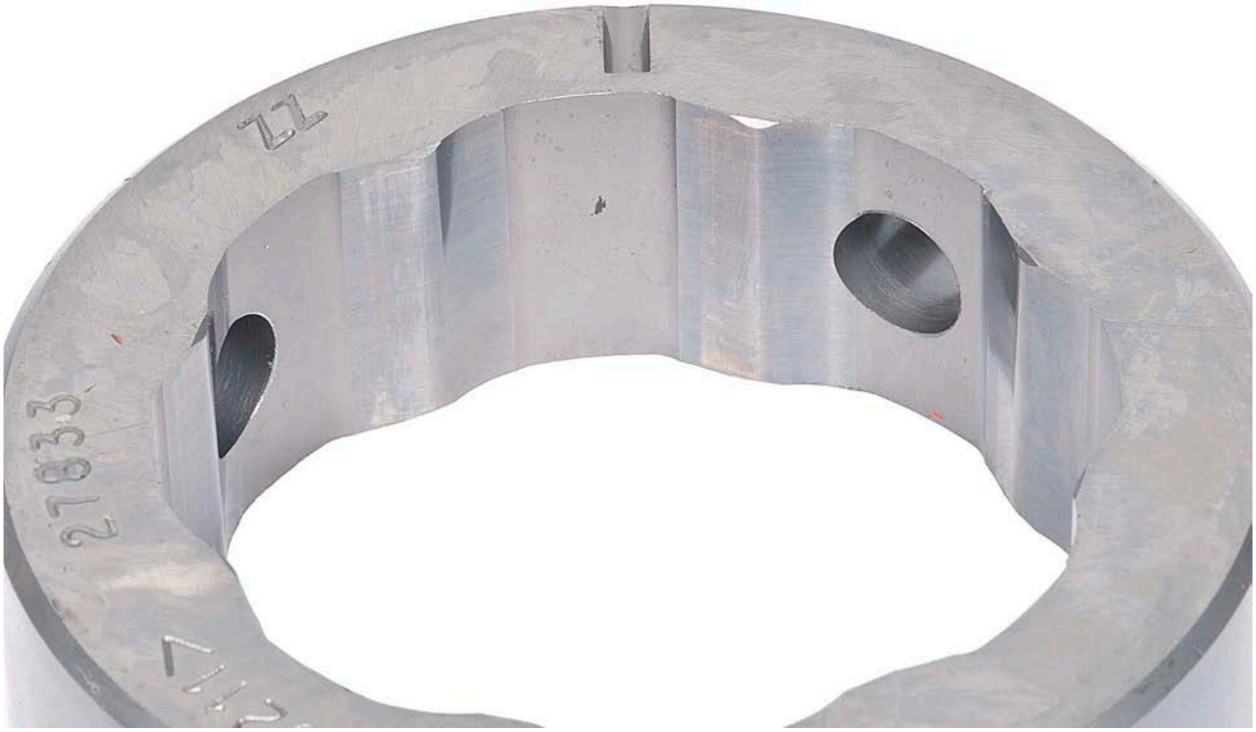
SN15848373 Piston Plungers, After

SN15848373 Thrust Washer, Before

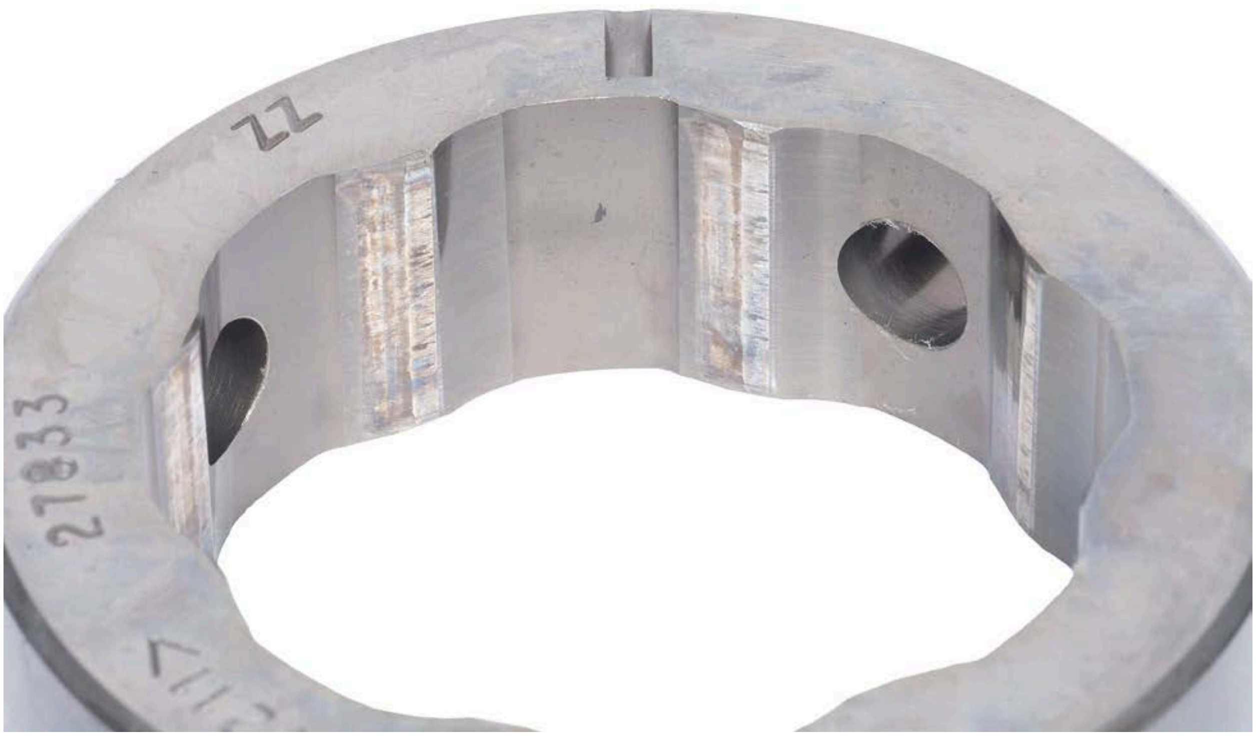
SN15848373 Thrust Washer, After

SN15848373 Governor Weight, Before

SN15848373 Governor Weight, After



SN15848373 Cam Ring, Before



SN15848373 Cam Ring, After

SN15848373 Eccentric Ring, Before

SN15848373 Eccentric Ring, After

SN15848373 Rotor (Front), Before

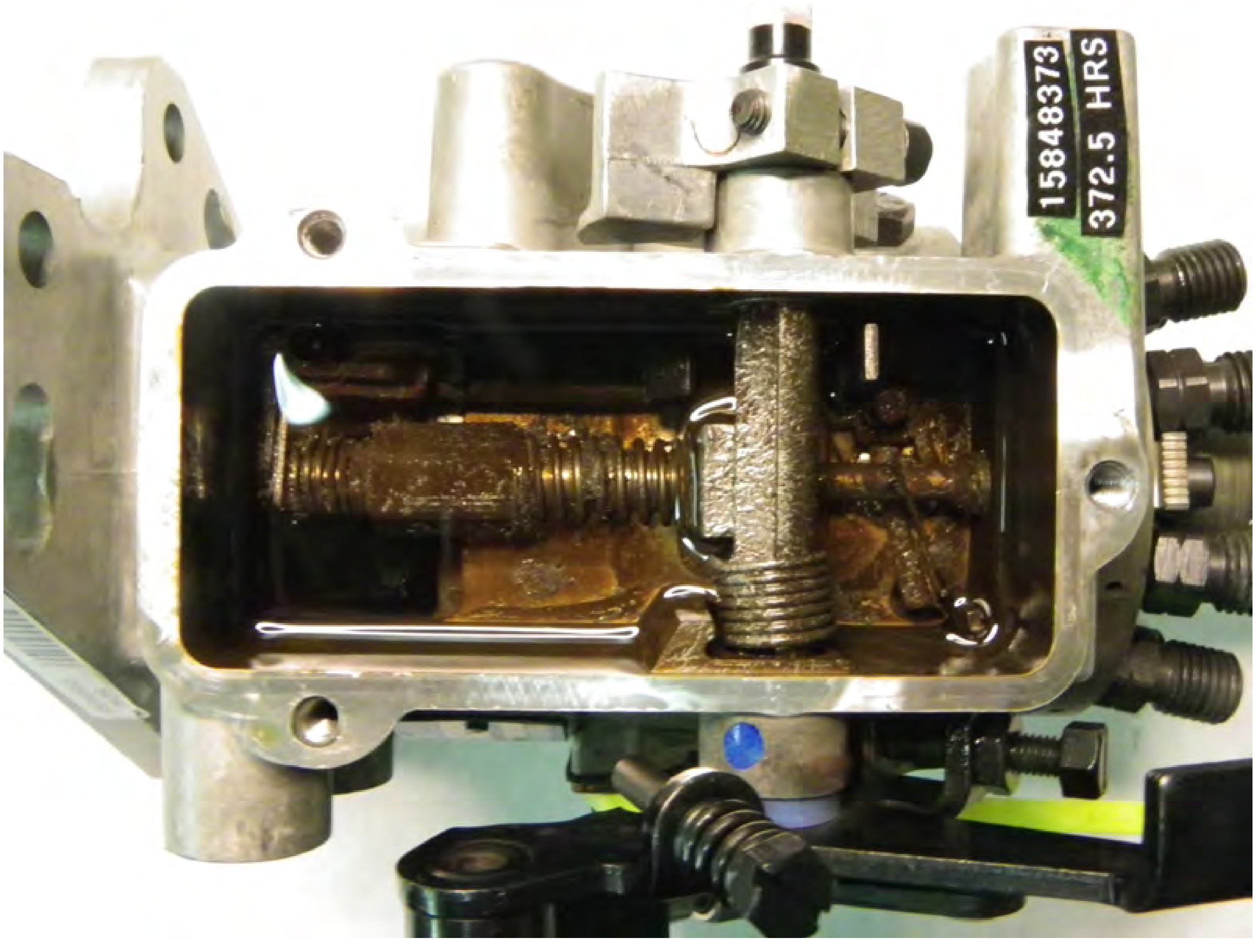
SN15848373 Rotor (Front), After

SN15848373 Rotor (Back), Before

SN15848373 Rotor (Back), After

SN15848373 Drive Tang, Before

SN15848373 Drive Tang, After

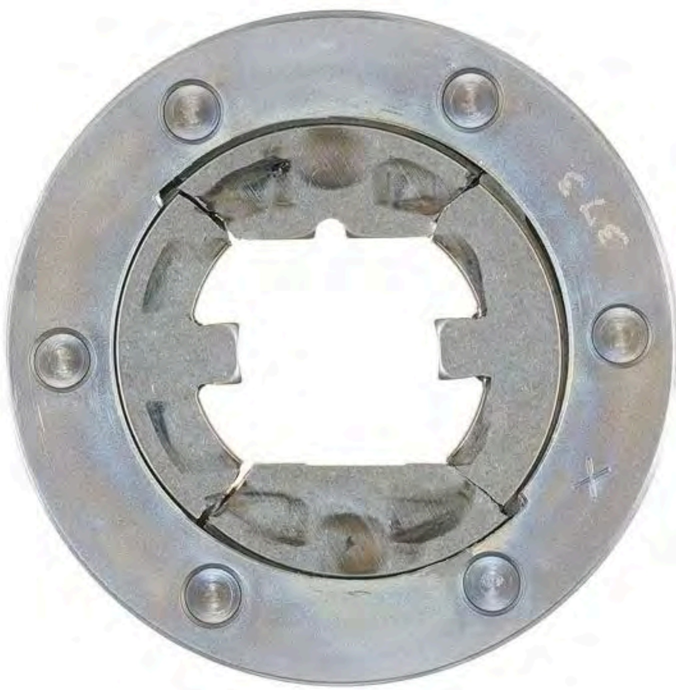


SN15848373 Governor Assembly

SN15848373 Rotor Drive Slot

SN15848373 Rotor Drive Slot Spring

SN15848373 Weight Cage



SN15848373 Weight Cage Back